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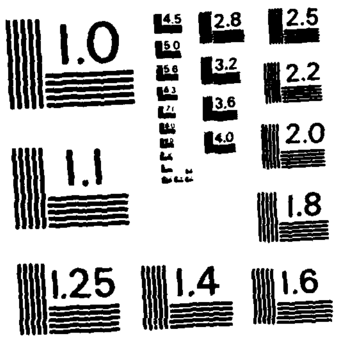
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DCN 84-212-027-04-02

Volume I

AD-A160 093

INSTALLATION RESTORATION PROGRAM

PHASE II - CONFIRMATION/QUANTIFICATION

STAGE 1

FINAL REPORT

FOR

TINKER AFB, OKLAHOMA

AIR FORCE LOGISTICS COMMAND
WRIGHT-PATTERSON AFB, OHIO

SEPTEMBER, 1985

PREPARED BY

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SUMMARY

Background and Purpose

The Department of Defense (DOD) is conducting a nation-wide program to evaluate past waste disposal practices on DOD property, control the migration of hazardous contaminants, and to control hazards that may result from these past waste disposal practices. This program, the Installation Restoration Program (IRP), consists of four phases: Phase I, Initial Assessment/Record Search; Phase II, Problem Confirmation; Phase III, Technology Base Development; and Phase IV, Remedial Action. The United States Air Force (USAF) has initiated an IRP investigation at Tinker Air Force Base near Oklahoma City, Oklahoma.

Phase I studies for the Tinker AFB Installation Restoration Program were completed in April 1982. The purpose of the Phase I study was to conduct a records search for the identification of past waste disposal activities which may have caused ground-water contamination and the migration of contaminants off-base.

Fourteen individual sites at Tinker AFB were identified as possibly containing hazardous waste. The potential for adverse environmental consequences of each site was evaluated with a rating or scoring system. This system took into account such factors as the site environmental setting, the nature of the wastes present, past waste disposal practices and the potential for contaminant migration.

Of the fourteen individual sites identified, eight sites, comprising four zones, were selected for Phase II studies. Two additional problem areas, not addressed in Phase I, were added to the list of sites for Phase II studies. These are the Base water supply wells and the wells in Building 3001. Radian Corporation performed the Phase II (Stage 1) Field Evaluation under USAF Contract No. F33615-83-D-4001, Delivery Order 0004.

The purpose of the Phase II (Stage 1) investigation was to determine if environmental contamination has resulted from waste disposal practices at Tinker AFB. In addition, the investigation included an estimate of the magnitude and extent of contamination, the identification of environmental consequences of migrating pollutants, and the recommendation of additional investigations necessary to identify the magnitude, extent and direction of movement of discovered contaminants.

Authorization to proceed on the Tinker AFB Phase II (Stage 1) program was given on 12 September 1983. Following the initial site visit conducted on 29 September 1983, field activities were accomplished during November 1983. A second field season was completed during February-March, 1984. The field work consisted of the installation and sampling of eleven ground-water monitoring wells, electromagnetic surveys of two waste disposal sites, followed by coring and sampling of shallow soils at these sites, sampling and analysis of ground water from Tinker AFB water supply wells, and the investigation of trichloroethylene contamination in two Tinker AFB water supply wells.

Waste Disposal Practices

Management of wastes at Tinker AFB was reviewed as part of the Phase I investigation conducted in 1982. Results of the investigation show that waste generated during most of the history of Tinker AFB has generally been handled on-site; recent operations (since about 1980) have directed wastewater streams to treatment units on base prior to discharge and have contracted with private waste disposal firms to handle solid wastes. In addition, some drummed liquids are returned to Defense Property Disposal Office (DPDO). On-site disposal operations included the use of landfills for solid waste, industrial waste pits for the disposal of liquids and sludges, and other disposal sites for low-level radioactive materials.

Disposal of solid waste occurred from 1942 to 1979 at six locations across the southern part of the Base. The landfills, numbered 1 through 6, were constructed by excavating a series of parallel trenches, depositing

waste, and covering with soil. The depth of the trenches has not been accurately recorded; it is probable that the depth is largely related to the ease of excavation of the shallow soil above shale bedrock, generally 10 to 15 feet below land surface. The landfills are visible today as features slightly elevated above the surrounding topography, with a hummocky surface corresponding to the former trenches that have undergone differential compaction. Most waste deposited in the landfill consisted of general base refuse, paper, trash, construction debris, and garbage. Table 1 identifies the features of each landfill and lists the probable contents at each site.

Liquid wastes and sludges generated during the period 1947-1965 were directed to industrial waste pits located in the southeast portion of the Base. These sites, Industrial Waste Pits 1 and 2, were used for the disposal of waste streams originating from the various aircraft maintenance shops at Tinker AFB. The streams were thought to contain high levels of heavy metals, and a variety of organic compounds (solvents and cleaners). The pits were probably unlined, with the materials in the pits periodically burned (Engineering Science, 1982).

Site Descriptions

The Phase II (Stage 1) Field Evaluation was organized by zones; each zone consisting of one or more waste disposal sites grouped together geographically or functionally. Zone 1 consists of four landfills, Landfills 1, 2, 3 and 4, located on the southwest part of the Base. Zone 2 consists of two landfills (Landfills 5 and 6) on the south side of the Base on opposite sides of the N-S runway. Zones 3 and 4 are the sites of Industrial Waste Pits Nos. 2 and 1, respectively, on the southeast part of the Base. Zone 5 consisted of the activity involved in the sampling of all water-supply wells at Tinker; and Zone 6 consisted of the evaluation of trichloroethylene in water-supply wells 18 and 19 located in Building 3001. The locations of the zones of investigation are shown on Figure 1.

TABLE 1. SUMMARY OF LANDFILLS AT TINKER AIR FORCE BASE (Engineering Science, 1982)

Landfill	Period of Operation	Approximate Area (Acres)	Types of Wastes	Estimate Quantity (yd^3)	Method of Operation	Closure Status	Geological Setting	Surface Drainage	Comments
1	1942-1945	1.2	General refuse	30,000	Burning, Trench	Closed, covered with earth, vegetation	Fine-grained sandstone; shale and mudstone	To Crutcho Creek	Some water ponding due to differential settling in trenches
2	1945-1952	20	General refuse, probably some industrial waste	500,000	Trench	Closed, covered with earth, vegetation	Fine-grained sandstone; shale and mudstone	To Crutcho Creek	A large pond is present above parts of the landfill
3	1952-1961	8	General refuse, probably some industrial waste	200,000	Trench	Closed, covered with earth	Fine-grained sandstone; shale and mudstone	To Crutcho Creek	Now used as storage area for hardfill and dirt
4	1961-1968	16	General refuse, probably some industrial waste, and POL sludges	400,000	Trench	Closed, covered with earth, partial vegetation	Fine-grained sandstone; shale and mudstone	To Crutcho Creek	Leachate occasionally visible along west side of landfill. Past leachate samples show high mercury and phenols.
5	1968-1970	3	General refuse, probably some industrial waste	75,000	Trench	Closed, covered with earth, vegetation	Fine-grained sandstone; shale and mudstone	To Crutcho Creek	Some leachate reported along side of landfill near creek.
6	1970-1979	11	General refuse, probably some industrial waste, and industrial waste treatment sludge	500,000	Trench	Closed, covered with earth, partial vegetation	Terrace; sand, silt, clays	To Soldier Creek	Covered and graded. No waste visible.

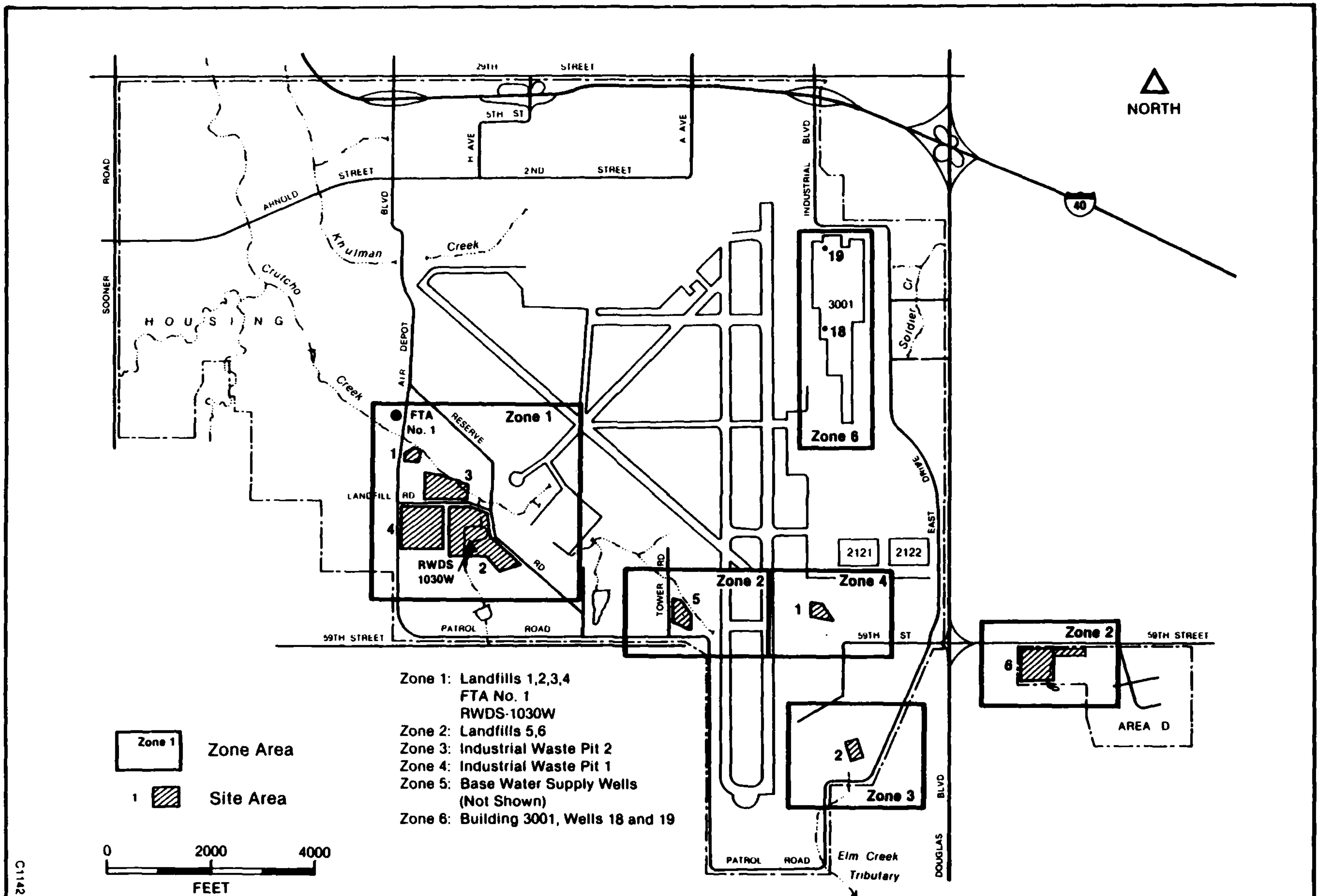

Figure 1. Zones of Investigation, Tinker, AFB.

Zone 1

Zone 1 consists of four individual landfills on the southwest side of the Base. The landfills, numbered from 1 to 4, were active from 1942 to 1968; all are closed, covered with soil, and vegetated. The landfills are clearly visible from the ground and are characterized by elevated (3-8 feet above the surrounding land), irregular surfaces with elongate depressions corresponding to former trenches, areas of patchy vegetation, and isolated zones of leachate emergence at the surface margins of the fills.

Prior to the Phase II (Stage 1) work, a series of ground water monitoring wells had been installed near Zone 1, primarily on the northeast side of the zone along Crutcho Creek. These wells are shallow, averaging approximately 25 feet in depth and are completed in deposits influenced by conditions in the creek. Conditions along the creek are adequately monitored by these wells.

Zone 2

Zone 2 consists of Landfills 5 and 6 at Tinker AFB; these widely-separated sites are located at the southern end of the Base. Landfill 5 is near the intersection of Patrol Road and Tower Road; it is bordered on the northeast by Crutcho Creek, on the west by Tower Road, and on the south by Building 1141. Three ground-water monitoring wells completed in the shallow alluvium existed prior to this study along Crutcho Creek; these wells provide ample coverage of ground-water conditions on the northeast side of the landfill.

Landfill 6 is approximately one-half mile east of the main Base (on AF leased property), south of 59th Street. Shallow ground-water monitoring wells have been installed at two locations along 59th Street north of the landfill. Additional ground-water data are available from several wells located north of 59th Street and south of Interstate 40.

Zone 3

Zone 3 is the former site of a surface impoundment located north of Patrol Road (betwen the main N-S runway and Douglas Boulevard) on the south side of the Base. The impoundment, Industrial Waste Pit 2, was in operation from 1958 to 1965. The pit received large quantities (i.e., more than 85 55-gallon drums) of waste oils, cyanides, chromates, phenols, solvents and waste acids and alkalies. No data are available concerning construction of the pit. It has been closed and the land surface regraded to approximate original contours. Grass now covers the site, obscuring the original limits of the pit.

Zone 4

Zone 4 encompasses Industrial Waste Pit 1 at Tinker AFB. The site is located in the south-cental portion of the Base. This pit, in operation from 1947 to 1958, received industrial wastes similar to those in Industrial Waste Pit No. 2 (Zone 3).

Zone 5

Activities in Zone 5 consisted of sampling all Base water supply wells. Tinker AFB presently obtains water supplies from a system of 27 water wells constructed along the east and west Base boundaries. All Base wells are completed in the Garber-Wellington Aquifer. Base wells range from 700 to 900 feet in depth, with yields ranging from 205 to 250 gallons per minute. The wells incorporate multiple screens, deriving water supplies from sand zones that vary in thickness from 103 to 184 feet (Wickersham, 1979).

Zone 6

Activities in Zone 6 consisted of evaluating the occurrence of trichloroethylene in Tinker AFB water supply wells 18 and 19 located in Building 3001.

Sampling and Analytical Program

The sampling program at Tinker consisted of the collection of soil and water. Samples of soil were retrieved from boreholes located at Zones 3 and 4. Samples of water were collected from various locations: existing monitoring wells installed along Crutcho Creek, monitoring wells installed at Zones 1, 2, 3 and 4 as part of this Phase II (Stage 1) IRP investigation, a leachate seep at Landfill 4, the recreational lake in Zone 1, and Base water supply wells.

All samples were transported to Radian Analytical Services for analysis. The schedule of analyses is summarized on Table 2.

Field Program

Various field activities were performed at Tinker Air Force Base in support of the IRP Phase II (Stage 1) investigation. The activities consisted of the completion of eleven deep and four shallow ground-water monitor wells, performance of two ground conductivity (electromagnetic) surveys, and split-spoon soil sampling of two waste sites. The periods of performance of the field activities were November 1983 and February-March 1984.

The following paragraphs contain descriptions of the various field techniques used in the Tinker AFB Phase II investigation. These techniques included geophysical surveying, hollow-stem augering and air rotary drilling, monitor well installation, and soil and ground-water sampling.

Geophysical Surveying: Geophysical surveying was performed in order to accurately define the area of investigation at two buried industrial waste pits (Zone 3 - Industrial Waste Pit No. 2 and Zone 4 - Industrial Waste Pit No. 1). The two sites are currently vacant land; no surface remnants of the waste disposal facilities are visible. The geophysical technique selected for the investigation consisted of an electromagnetic survey using ground conductivity sensors.

TABLE 2. ANALYTICAL SCHEDULE FOR SOIL AND WATER SAMPLES, TINKER AFB

Parameter	Zones
Barium	2
Iron	1, 2
Manganese	1
Total Organic Halogen (TOX)	1, 2, 3, 4
Oil and Grease	1, 2, 3, 4
Total Organic Carbon (TOC)	1, 2, 3, 4
Cyanide	1, 2, 3, 4
Metals (Cd, Cr, Ni, Cu, Zn, Pb, Hg)	1, 2, 3, 4
Volatile Hydrocarbons (EPA 601)	5
Phenol	1, 2, 3, 4
Pesticides and Herbicides	1, 2
Trichloroethylene and tetrachloroethylene (EPA 601)	6
Acid Neutral Extractable Organic Priority Pollutants (modified EPA 625)	
- selected wells	1, 2, 3, 4, 5
- selected soils	3, 4
Volatile Organic Priority Pollutants (EPA 624)	
- selected wells	5

Drilling Techniques: Drilling and coring at Tinker AFB were accomplished using two techniques: air-rotary drilling for deep monitor wells, and hollow-stem augering for shallow exploratory borings and monitor wells. Each method was selected on the basis of the anticipated depth of completion, need for detailed control of sampling and water-level observations, and geologic conditions expected at various depths.

The air rotary drilling was performed with either a Failing 1250 (November activities) or a Failing 1500 (February-March activities) truck-mounted rig. A 6-7/8 inch tricone bit was used to drill the borehole to a depth of 10 feet below the first ground water encountered. No drilling fluids or additives were used in the drilling program. The decision to complete the borehole and install the screen and casing for the monitor well was made on the basis of relative water level (with respect to the approximate predicted regional water level), the likelihood of perched water above a regional water table, and the representativeness of the water table in terms of evaluating the impact of the waste disposal site on the quality of ground water.

A hollow-stem auger drilling rig, the Mobile B-50, was used at Zones 3 (Industrial Waste Pit 2) and 4 (Industrial Waste Pit 1) to perform shallow coring in the vicinity of the pits. The hollow-stem method allowed for an accurate examination of soil conditions, identification of waste material and contaminated soil, and recovery of soil samples. The holes were drilled dry; no drilling fluids or additives were used. Samples of soil and waste were collected with a split-spoon sampler, a hollow tube driven in advance of the auger at regular intervals (ASTM D-1586).

Ground-Water Sampling: Ground-water samples were collected for analysis from the 11 ground-water monitor wells installed under Phase II (Stage 1) (this program), eight existing ground-water monitor wells, and 20 Base supply wells.

Other Sampling: In addition to the monitor well sampling, selected surface water samples were also collected. Leachate seeps were sampled by excavating a small trench at the site of the seep and allowing water to accumulate. The surface impoundment at Landfill 2 was sampled by compositing grab samples from four randomly selected locations within the pond. Samples were submitted for the same chemical analyses as were the ground-water samples. An aliquot of the composited pond sample was also provided to the Base Bioenvironmental Engineering staff for radiochemical analysis.

Results of Analysis

In general, the Phase II (Stage 1) investigation documented only limited contaminant movement from the waste sites investigated. However, analytical data supplied by the State of Oklahoma suggest that volatile organic priority pollutants may be important species at all waste disposal sites. A summary of the analytical data for Zones 1 through 4 is provided in Table 3.

With the exception of wells in the vicinity of Building 3001, all Base water supply wells appear to be unaffected by contaminant migration from Base waste disposal sites.

Based on the results of the Phase II (Stage 1) investigation, conditions at Zone 6 consist of a zone of contamination, dominantly trichloroethylene, of unknown source and extent, in the vicinity of Building 3001. The occurrence of contamination is limited to relatively shallow zones.

Recommendations

Based on the findings of this study, Radian recommends certain follow-up investigations to resolve remaining issues. These recommendations and issues addressed are listed in Table 4, in order of priority. The selection and prioritization criterion is the verification of impacts on possible receptors.

TABLE 3. SUMMARY OF CHEMICAL ANALYSES, ZONES 1 THROUGH 4, TINKER AFB

Parameter (mg/L)	Range of Observations						Regulatory Standard or Criteria
	Zone 1			Zone 2	Zone 3	Zone 4	
	Ground Water	Leachate	Pond				
Barium	-[1]	-	-	0.21-0.45	-	-	1.0
Cadmium	<0.002-0.008	<0.002	<0.002	<0.002-0.006	<0.002-2.2	0.002	0.010
Cyanide	<0.01-<0.02	<0.01	<0.02	<0.01	<0.01	0.01	0.2
Chromium	<0.001-0.005	0.023	<0.001	<0.001	<0.001-12	0.001-0.014	0.05
Copper	<0.001-0.009	<0.001	<0.001	<0.001	<0.001-0.15	0.001-0.021	1.0
Iron	<0.008-0.025	5.0	0.25	<0.008-0.23	-	-	0.3
Mercury	<0.0005-0.0006	<0.0005	<0.0005	<0.0004-0.0005	0.0004-0.0006	0.0002-0.0004	0.002
Manganese	<0.013-2.3	0.33	0.010	-	-	-	0.05
Nickel	<0.003-0.008	0.73	<0.003	<0.003	<0.003-82	0.008-0.009	0.013
Oil & Grease	<1	<1	<1	<1	<1-70	<1	-
Lead	<0.002	<0.002	<0.002	<0.002	<0.002-3.3	0.006-0.022	0.05
Phenol	<0.005	0.21	<0.005	<0.005	<0.005-80	<0.005	3.5
Total Organic Carbon	<1-37	340	5	<1-9	<1-4000	<1-43	-
Total Organic Halogen	<0.01-0.20	1.5	<0.01	<0.01	<0.01-3.4	<0.01-0.06	-
Zinc	<0.003-0.044	<0.003	<0.003	<0.003-0.34	0.016-29	1.2-1.4	5.0
Herbicides	ND[2]	ND	ND	ND	-	-	-
Pesticides (EPA Method 608)	ND	ND	ND	ND	-	-	-
Acid/Neutral Extractable Organic Priority Pollutants (Modified EPA Method 625) (compounds detected in µg/l)	ND	-	-	butyl benzyl phthalate 2.3	1,2 dichlorobenzene 20 phenol 220	phenol 1.0 -	- -

[1]- = Not analyzed.
[2]ND = Not detected.

TABLE 4. RECOMMENDATIONS

Problem Area or Site No.	Recommended Action	Rationale
Zone 6	Investigate hydrogeologic conditions and contaminant occurrence in the vicinity of Building 3001, as provided in Delivery Order 21.	Occurrence of TCE in Well 18 suggests shallow source/occurrence. Need to document area of contamination and movement.
Zone 2 (Landfill 6)	Investigate hydrogeologic conditions and contaminant occurrence in the vicinity of Landfill 6, as provided in Delivery Order 21.	Hydrocarbon contamination reported by Oklahoma State Department of Health in a private well, immediately northeast of Landfill 6. Possible source is Landfill 6.
All Zones	Investigate the occurrence of volatile halocarbons and aromatics in all monitor wells by resampling and analysis by EPA Methods 601 and 602 (double column).	Oklahoma State Department of Health data suggest existence of volatile contaminants in ground water.
Zone 1	Investigate the seasonal variations in water quality in the existing monitor wells along Crutcho Creek by conducting a quarterly sampling program for a period of one year. Analyses should be for total organic carbon, total organic halogen, and the metals on the parameter list in the current Statement of Work, Fe, Mn, Cd, Cr, Ni, Cu, Zn, Pb and Hg.	Data from original investigation do not agree with Phase II (Stage 1) data.

RADIAN
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1.0 INTRODUCTION

The Department of Defense (DOD) is conducting a nation-wide program to evaluate past waste disposal practices on DOD property, control the migration of hazardous contaminants, and to control hazards that may result from these past waste disposal practices. This program, the Installation Restoration Program (IRP), consists of four phases: Phase I, Initial Assessment/ Record Search; Phase II, Problem Confirmation; Phase III, Technology Base Development; and Phase IV, Remedial Actions. The United States Air Force (USAF) has initiated an IRP investigation at Tinker Air Force Base near Oklahoma City, Oklahoma; Radian Corporation has performed the Phase II (Stage 1) Field Evaluation under USAF Contract No. F33615-83-D-4001, Delivery Order 0004.

1.1 Purpose of the Investigation

The purpose of the Phase II (Stage 1) investigation was to determine if environmental contamination has resulted from past waste disposal practices at Tinker AFB. In addition, the purpose of the investigation included an estimate of the magnitude and extent of contamination, the identification of environmental consequences of migrating pollutants, and the recommendation of additional investigations to identify the magnitude, extent and direction of movement of discovered contaminants.

1.2 Duration of the Program

Authorization to proceed on the Tinker AFB Phase II (Stage 1) program was given on 12 September 1983. Following the initial site visit conducted on 29 September 1983, field activities were initiated during November 1983. A second field season was completed during February-March, 1984. The field work consisted of the installation and sampling of ground-water monitoring wells, electromagnetic surveys of two waste disposal sites, coring and sampling of shallow soils at suspected waste disposal sites, sampling and analysis of ground water from Tinker AFB water supply wells, and the investigation of trichloroethylene contamination in two Tinker AFB water supply wells.

1.3 Waste Disposal Practices

Management of wastes at Tinker AFB was reviewed as part of the Phase I investigation conducted in 1982. Results of the investigation show that waste generated during most of the history of Tinker AFB has generally been handled on-site; recent operations (since about 1980) have directed wastewater streams to treatment units on base prior to discharge and have contracted with private waste disposal firms to handle solid wastes. On-site disposal operations included the use of landfills for solid waste, industrial waste pits for the disposal of liquids and sludges, and other disposal sites for low-level radioactive materials. Figure 1-1 illustrates the location of the major waste disposal sites at Tinker, together with their zones of investigation established for this study.

Disposal of solid waste occurred from 1942 to 1979 at six locations across the southern part of the Base. The landfills, numbered 1 through 6, were constructed by excavating a series of parallel trenches, depositing waste, and covering with soil. The depth of the trenches has not been accurately recorded; it is probable that the depth is largely related to the ease of excavation of the shallow soil above shale bedrock, generally 10 to 15 feet below land surface. The landfills are visible today as features slightly elevated above the surrounding topography, with a hummocky surface corresponding to the former trenches that have undergone differential compaction. Most waste deposited in the landfill consisted of general base refuse, paper, trash, construction debris, and garbage. Table 1-1 identifies the features of each landfill and lists the probable contents at each site.

Liquid wastes and sludges generated during the period 1947-1965 were directed to industrial waste pits located in the southeast portion of the Base. These sites, Industrial Waste Pits 1 and 2 (IWP 1 and IWP 2), were used for the disposal of waste streams originating from the various aircraft maintenance shops at Tinker AFB. The streams were thought to contain high levels of heavy metals, and a variety of organic contaminants (solvents and cleaners). The pits were probably unlined, with the materials in the pits periodically burned.

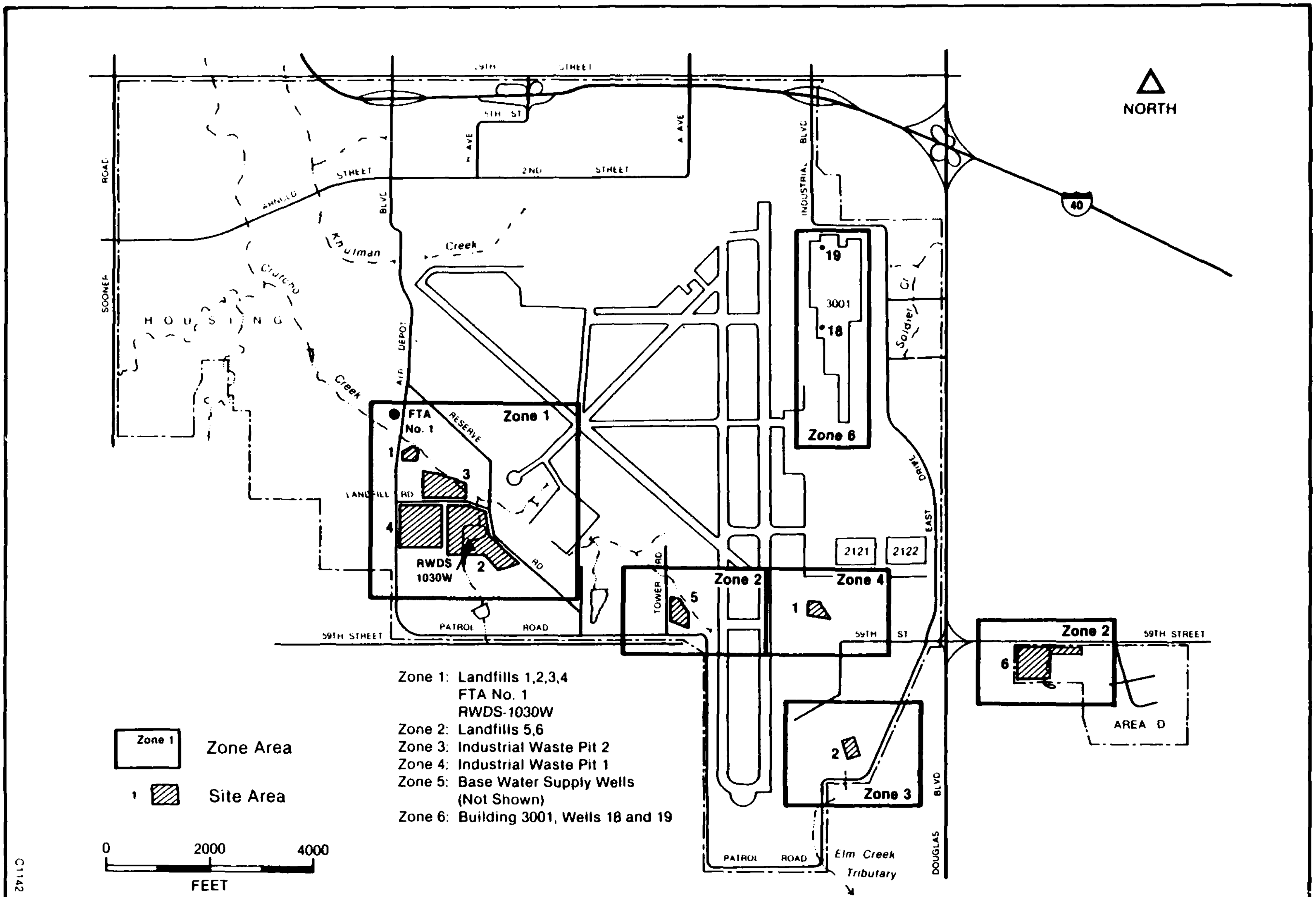

Figure 1-1. Locations of Waste Disposal Areas, Tinker AFB.

TABLE 1-1. SUMMARY OF LANDFILLS AT TINKER AIR FORCE BASE (Engineering-Science, 1982)

Landfill	Period of Operation	Approximate Area (Acres)	Types of Wastes	Estimate Quantity (yd^3)	Method of Operation	Closure Status	Geological Setting	Surface Drainage	Comments
1	1942-1945	1.2	General refuse	30,000	Burning, Trench	Closed, covered with earth, vegetation	Fine-grained sandstone; shale and mudstone	To Crutcho Creek	Some water ponding due to differential settling in trenches
2	1945-1952	20	General refuse, probably some industrial waste	500,000	Trench	Closed, covered with earth, vegetation	Fine-grained sandstone; shale and mudstone	To Crutcho Creek	A large pond is present above parts of the landfill
3	1952-1961	8	General refuse, probably some industrial waste	200,000	Trench	Closed, covered with earth	Fine-grained sandstone; shale and mudstone	To Crutcho Creek	Now used as storage area for hardfill and dirt
4	1961-1968	16	General refuse, probably some industrial waste, and POL sludges	400,000	Trench	Closed, covered with earth, partial vegetation	Fine-grained sandstone; shale and mudstone	To Crutcho Creek	Leachate occasionally visible along west side of landfill. Past leachate samples show high mercury and phenols.
5	1968-1970	3	General refuse, probably some industrial waste	75,000	Trench	Closed, covered with earth, vegetation	Fine-grained sandstone; shale and mudstone	To Crutcho Creek	Some leachate reported along side of landfill near creek.
6	1970-1979	11	General refuse, probably some industrial waste, and industrial waste treatment sludge	500,000	Trench	Closed, covered with earth, partial vegetation	Terrace; sand, silt, clays	To Soldier Creek	Covered and graded. No waste visible.

1.4 Site Descriptions

The Phase II (Stage 1) Field Evaluation was organized by zones; each zone consisting of one or more waste disposal sites grouped together geographically or functionally. Zone 1 consists of four landfills, Landfills 1, 2, 3 and 4, located on the southwest part of the Base as well as Fire Training Area No. 1 and Radiological Waste Disposal Site (RWDS) 1030W. Zone 2 consists of two landfills (Landfills 5 and 6) on the south side of the Base on opposite sides of the N-S runway. Zones 3 and 4 are the sites of industrial waste pits Nos. 2 and 1, respectively, on the southeast part of the Base. Zone 5 consisted of the activity involved in the sampling of all water-supply wells at Tinker; and Zone 6 consisted of the evaluation of trichloroethylene in water-supply wells 18 and 19 located in Building 3001. The locations of the zones of investigation are shown on Figure 1-2.

Zone 1

Zone 1 consists of four individual landfills on the southwest side of the Base. The landfills, numbered from 1 to 4, were active from 1942 to 1968; all are closed, covered with soil, and vegetated. The landfills are clearly visible from the ground and are characterized by elevated (3-8 feet above the surrounding land), irregular surfaces with elongate depressions corresponding to former trenches, areas of patchy vegetation, and isolated zones of leachate emergence at the surface margins of the fills. Also included within Zone 1 are Fire Training Area No. 1 and Radiological Waste Disposal Site 1030W.

Prior to the Phase II (Stage 1) work, a series of ground water monitoring wells had been installed near Zone 1, primarily on the northeast side of the zone along Crutcho Creek. These wells are shallow, averaging approximately 25 feet in depth and are completed in deposits influenced by conditions in the creek. Conditions along the creek are adequately monitored by these wells.

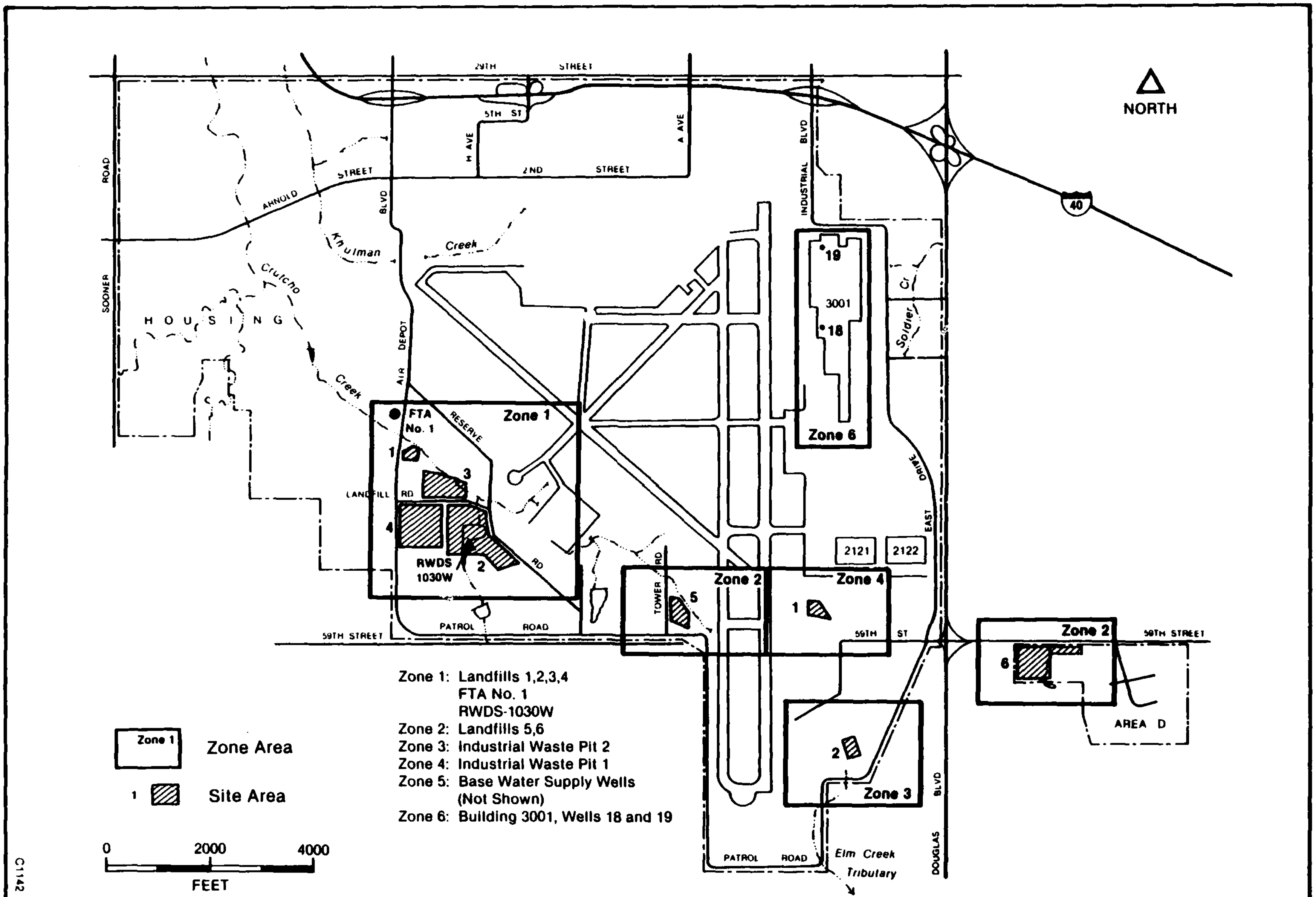

Figure 1-2. Zones of Investigation, Tinker AFB.

Zone 2

Zone 2 consists of Landfills 5 and 6 at Tinker; these widely-separated sites are located at the southern end of the Base. Landfill 5 is near the intersection of Patrol Road and Tower Road; it is bordered on the northeast by Crutcho Creek, on the west by Tower Road, and on the south by Building 1141. Three ground-water monitoring wells completed in the shallow alluvium exist along Crutcho Creek; these wells provide ample coverage of ground-water conditions on the northeast side of the landfill.

Landfill 6 is approximately one-half mile east of the main Base (on AF leased property), south of 59th Street. Shallow ground-water monitoring wells have been installed at two locations along 59th Street, north of the landfill. Additional ground-water data are available from several wells located north of 59th Street and south of Interstate 40.

Zone 3

Zone 3 is the former site of a surface impoundment located north of Patrol Road (between the main N-S runway and Douglas Boulevard) on the south side of the Base. The impoundment, Industrial Waste Pit 2 (IWP2) was in operation from 1958 to 1965. The pit received large quantities of waste oils, cyanides, chromates, phenols, solvents and waste acids and alkalies. No data are available concerning construction of the pit. It has been closed and the land surface regraded to approximate original contours. Grass now covers the site, obscuring the original limits of the pit.

Zone 4

Zone 4 encompasses Industrial Waste Pit 1 at Tinker AFB. The site is located in the south-central portion of the Base. This pit, in operation from 1947 to 1958, received industrial wastes similar to those in Industrial Waste Pit No. 2 (Zone 3).

Zone 5

Activities in Zone 5 consisted of sampling all water supply wells at Tinker AFB. Tinker AFB presently obtains water supplies from a system of 27 water wells constructed along the east and west Base boundaries. All Base wells are completed in the Garber-Wellington Aquifer. Base wells range from 700 to 900 feet in depth, with yields ranging from 205 to 250 gallons per minute. The wells incorporate multiple screens, deriving water supplies from sand zones that vary in thickness from 103 to 184 feet (Wickersham, 1979).

Zone 6

Activities in Zone 6 consisted of evaluating the occurrence of trichloroethylene in water supply wells 18 and 19 located in Building 3001.

Sampling and Analytical Program

The *sampling program* at Tinker consisted of the collection of soil and water. Samples of soil were retrieved from boreholes located at Zones 3 and 4; each sample of soil was collected using a split-spoon sampler driven into the substrate with a 140 pound hammer (standard penetration test). The samples of soil were placed individually in glass jars and frozen. Samples of water were collected from various locations: existing monitoring wells installed along Crutcho Creek, monitoring wells installed at Zones 1, 2, 3, and 4 as part of this Phase II (Stage 1) IRP investigation, the recreational lake at Zone 1, and Base water supply wells. Depending on the location the samples of water were collected from an existing in-place pump, a small-diameter portable pump, or a Teflon bailer.

All samples were transported to Radian Analytical Services for analysis. The schedule of analyses is summarized on Table 1-2, with complete descriptions provided in Section 3.0.

TABLE 1-2. ANALYTICAL SCHEDULE FOR SOIL AND WATER SAMPLES, TINKER AFB.

Parameter	Zones
Barium	2
Iron	1, 2
Manganese	1
Total Organic Halogen (TOX)	1, 2, 3, 4
Cyanide	1, 2, 3, 4
Metals (Cd, Cr, Ni, Cu, Zn, Pb, Hg)	1, 2, 3, 4
Volatile Hydrocarbons (EPA 601)	5
Phenol	1, 2, 3, 4
Pesticides and Herbicides	1, 2
Trichloroethylene and tetrachloroethylene (EPA 601)	6
Acid Neutral Extractable Organic Priority Pollutants (Modified EPA 625)	
- Selected wells	1, 2, 3, 4, 5
- Selected soils	3, 4
Volatile Organic Priority Pollutants (EPA 624)	
- Selected wells	5

Investigation Personnel

The Tinker AFB IRP Phase II (Stage 1) investigation was conducted by several individuals at Austin offices of Radian Corporation. Marshall F. Conover, Program Manager, was responsible for the contractual administration of this program. The overall technical management was directed by William M. Little, Senior Engineer and Certified Professional Geological Scientist. Mr. Little was involved in the coordination of all activities of the program, including direct participation with USAF personnel in the areas of contract and technical matters. Field activities, consisting of the geophysical surveys, coring, and monitoring well installation work, were supervised by Lawrence N. French and Rick A. Belan, both Certified Professional Geological Scientists. Sampling activities were conducted by Kathey A. Ferland, Fred B. Blood and Debra L. Richmann. Cartographic and technical illustrations were prepared by Jill P. Rossi. Ann E. St.Clair provided senior technical staff review and editing. All of the above individuals were involved in the preparation of the draft and final reports. Resumes for these individuals are provided in Appendix K.

2.0 ENVIRONMENTAL SETTING

This discussion of the Tinker AFB environmental setting was principally derived from the Installation Restoration Program Phase I Records Search report (Engineering-Science, 1982). Information developed from that report is supplemented by the literature and the general findings of this study. The following sections describe the environmental setting of Tinker AFB. Basic features and history of the sites investigated in this study are also discussed here.

2.1 General Geographic Setting and Land Use

Tinker AFB is located in central Oklahoma, within the corporate limits of Oklahoma City and adjacent to the suburbs of Midwest City and Del City (Figure 2-1). Tinker AFB is bordered by Interstate 40 to the north, Douglas Boulevard to the east, Sooner Road to the west, and industrial and undeveloped land near S.E. 59th Street to the south. The general features of Tinker AFB are illustrated in Figure 2-2.

The Base lies within an area representing a transition from residential and industrial/commercial land use on the west to agricultural land on the east and south. The principal industrial use of the area southwest of the Base is the General Motors installation south of S.E. 59th Street.

2.2 Physiographic and Topographic Features

Tinker AFB is located within the Central Redbed Plains section of the Central Lowland Physiographic Province, an area characterized by nearly level to gently rolling hills, broad flat plains and well-entrenched main streams. Surface elevations in the Oklahoma City area range from 1,070 to 1,400 feet MSL; at Tinker AFB the elevations range from 1,210 feet MSL (at Crutcho Creek, near the northwest portion of the Base) to about 1,320 feet

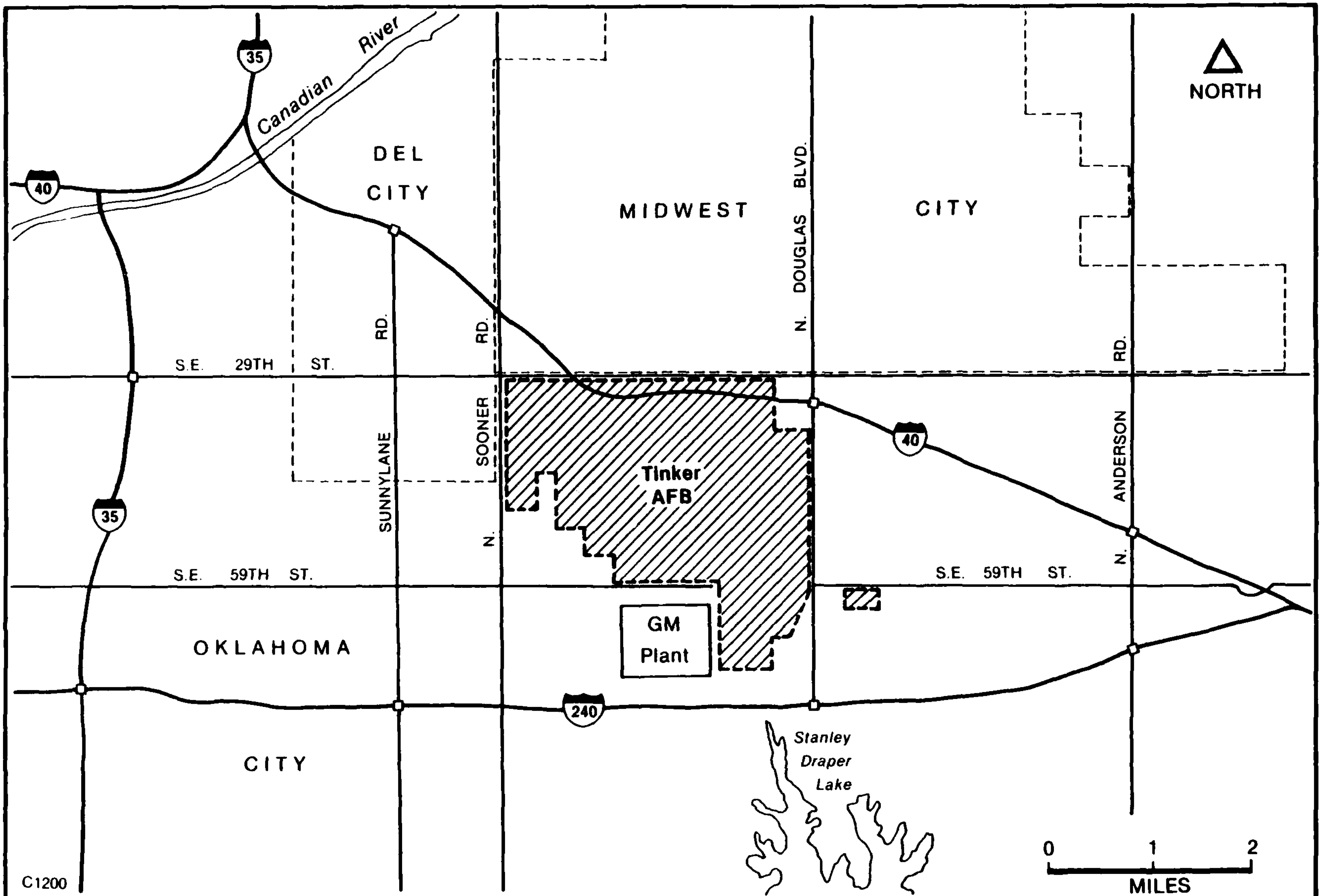

Figure 2-1. General Location Map, Tinker AFB.

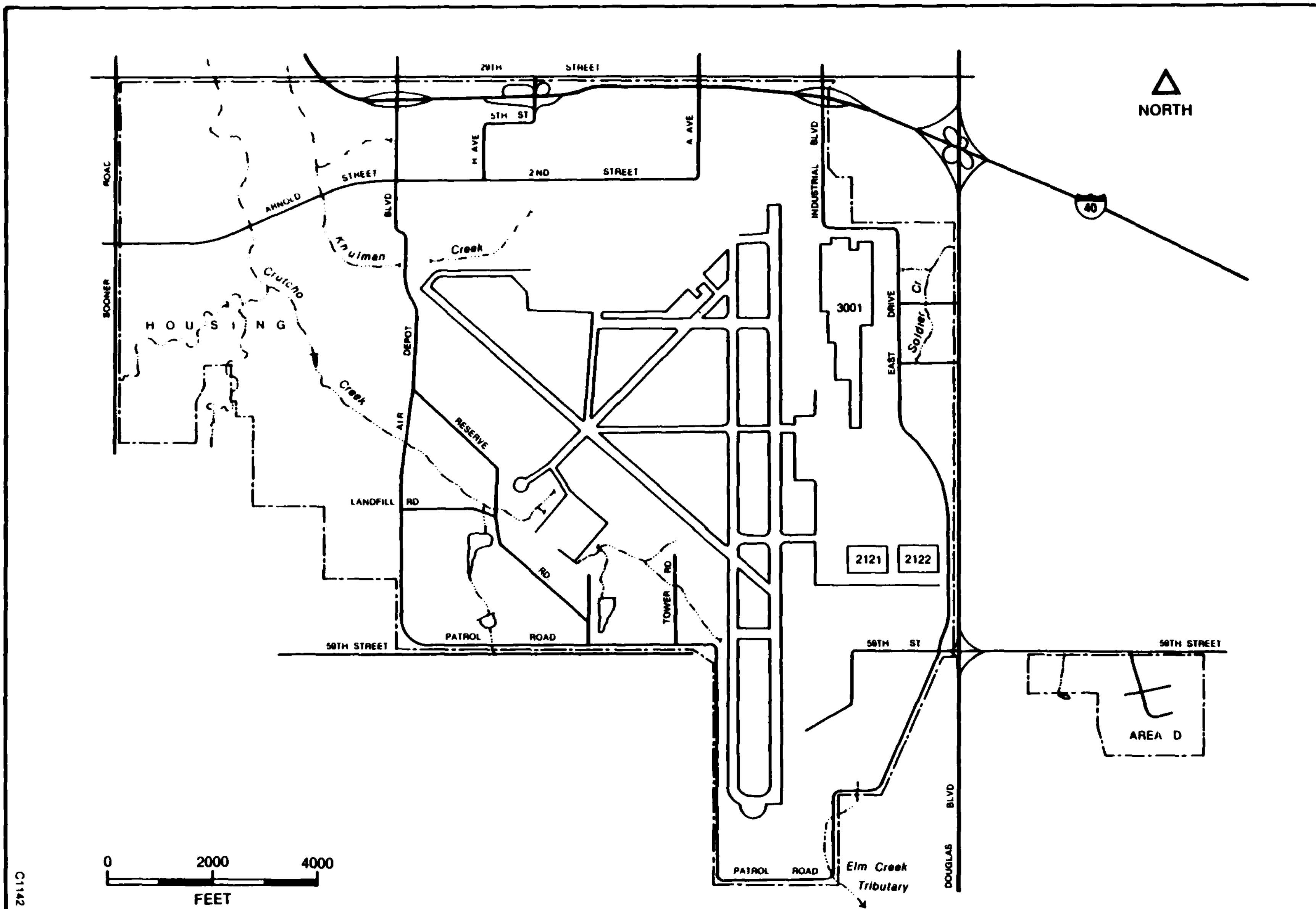

Figure 2-2. General Features of Tinker AFB.

MSL (at the southeast corner of the installation, south of 59th Street at Area "D"). Topographic features of the various sites investigated in this study are discussed in Section 4.0.

The principal drainages for Tinker AFB are Crutcho and Soldier Creeks. Most of the base is drained by Crutcho Creek and its tributary, Kuhlmann Creek. The eastern part of the base, near Douglas Boulevard and the Air Logistics Center, is drained by Soldier Creek. The extreme southern part of the Base is drained by Elm Creek, an intermittent stream. The drainage characteristics of the sites evaluated in this investigation are discussed in Section 4.0.

2.3 Geologic and Hydrogeologic Conditions

Surficial Soils

The surficial soils of Tinker AFB are described by the USDA, Soil Conservation Service (1969). The three major soil associations occurring on the installation are shown on Figure 2-3 and described on Table 2-1. The surface soils of the installation area are predominantly fine-grained and consist of two basic types: residual and alluvial. The residual soils associations, Darrell-Stephenville and Renfrow-Vernon-Bethany, are the product of in-place weathering of underlying bedrock. The alluvial materials (Dale-Canadian-Port Association) are stream-deposited silts and sands, whose occurrence is generally restricted to the floodplains of area streams.

Lithology

The physical distribution of significant geologic units relevant to this study are shown on Figure 2-4, which has been modified from the work of Bingham and Moore (1975). Tinker AFB geologic units are summarized on Table 2-2. Generally, the surfical geology of the north section of the installation is dominated by the Garber Sandstone, which crops out across a broad area of Oklahoma County. The surficial geology in the south portion of the Base is reportedly underlain by the Hennessey Group, consisting of the Kingman

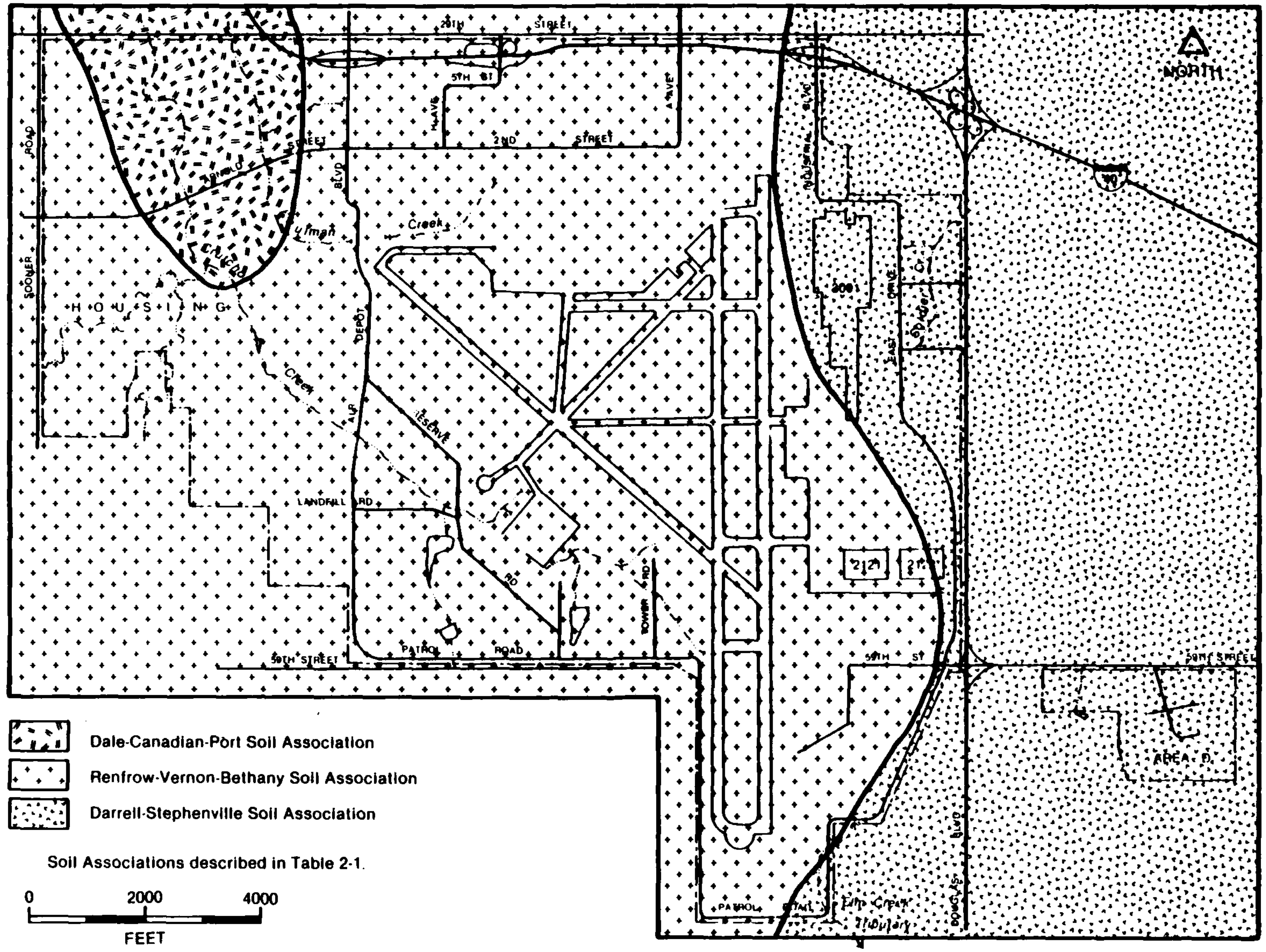

Figure 2-3. Soil Associations, Tinker AFB (USDA, Soil Conservation Service, 1969).

TABLE 2-1. TINKER AIR FORCE BASE SOIL ASSOCIATIONS

Association	Description	Thickness (in.)	Unified Class.	Permeability (in/hr*)
Darrell-Stephenville: loamy soils of wooded uplands.	Sandy loam Sandy clay loam Soft sandstone (Garber Sandstone)	12-54	SM,ML,SC	2.0-6.30
Renfrow-Vernon-Bethany: loamy and clayey soils on prairie uplands.	Silt loam - clay Clay loam Shale (Fairmont Shale)	12-60	ML,CL MH,CH	<0.06-0.20
Dale-Canadian-Port: loamy soils on low benches near large streams.	Fine sandy loam Silty clay loam Loam Clay loam	12-60	SM,ML,CL	0.05-6.30

SOURCE: USDA, Soil Conservation Service (1969).

* Although this characteristic of base soils is called "Permeability" by the Soil Conversation Service, it is actually a description of infiltration rates - the rate at which water moves through unsaturated earth materials.

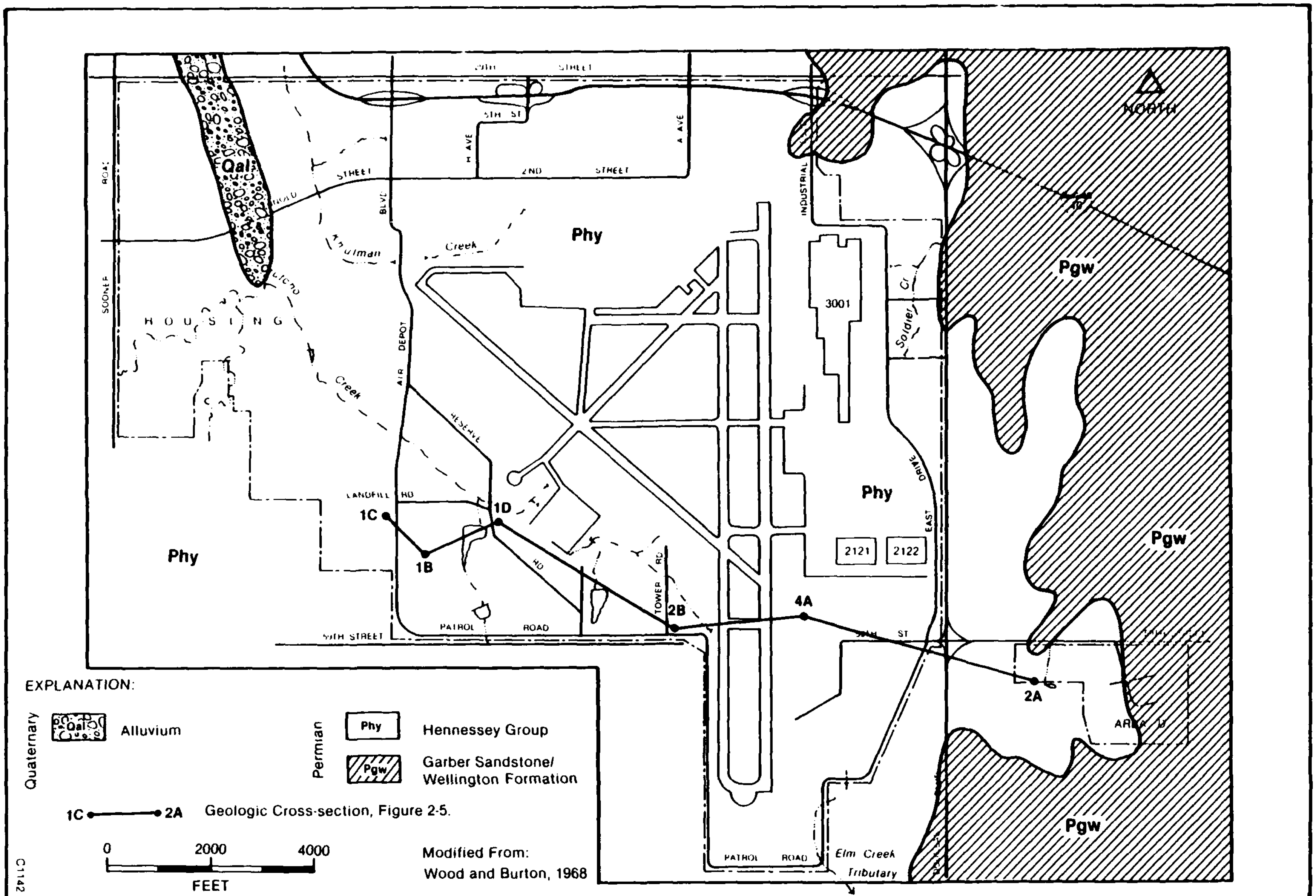

Figure 2-4. Geologic Map of Tinker AFB.

TABLE 2-2. MAJOR GEOLOGIC UNITS IN THE VICINITY OF TINKER AFB (Modified from Wood and Burton, 1968)

System	Series	Stratigraphic Unit	Thickness (feet)	Description and Distribution	Water-Bearing Properties
QUATERNARY	PLEISTOCENE AND RECENT	Alluvium	0-70	Unconsolidated and interfingering lenses of sand, silt, clay, and gravel in the flood plains and channels of streams.	Moderately permeable. Yields small to moderate quantities of water to wells in valleys of larger streams. Water is very hard, but suitable for most uses, unless contaminated by industrial wastes or oil-field brines.
		Terrace deposits	0-100	Unconsolidated and interfingering lenses of sand, silt, gravel, and clay that occur at one or more levels above the flood plains of the principal streams.	Moderately permeable. Locally above the water table and not saturated. Where deposits have sufficient saturated thickness, they are capable of yielding moderate quantities of water to wells. Water is moderately hard to very hard, but less mineralized than water in other aquifers. Suitable for most uses unless contaminated by oil field brines.
PERMIAN	LOWER PERMIAN	Hennessey Group (Includes Kingman Siltstone and Fairmont Shale)	700	Deep-red clay shale containing thin beds of red sandstone and white or greenish bands of sandy or limey shale. Forms relatively flat to gently rolling grass-covered prairies.	Poorly permeable. Yields meager quantities of very hard, moderately to highly mineralized water to shallow domestic and stock wells. In places water contains large amounts of sulfate.
		Garber Sandstone	500$\pm$	Deep-red to reddish-orange, massive and cross-bedded fine-grained sandstone interbedded with and interfingered with red shale and siltstone.	Poorly to moderately permeable. Important source of ground water in Cleveland and Oklahoma Counties. Yields small to moderate quantities of water to deep wells; heavily pumped for industrial and municipal uses in the Norman and Midwest City areas. Water from shallow wells hard to very hard; water from deep wells moderately hard to soft. Lower part contains water too salty for domestic and most industrial uses.
		Wellington Formation	500$\pm$	Deep-red to reddish-orange massive and cross-bedded fine-grained sandstone interbedded with red, purple, maroon, and gray shale. Base of formation not exposed in the area.	

Siltstone and the Fairmont Shale, as indicated on geologic maps by Miser (1959) and Bingham & Moore (1975) and confirmed by drilling in Phase IIB. The Fairmont Shale (Hennessey Group) strata, consisting predominantly of shale, are difficult to distinguish from upper portions of the underlying Garber Sandstone, which is reported to be shaly. The contact between the Fairmont Shale and Garber Sandstone is gradational throughout the Oklahoma City area. Published geologic maps differ in the interpretation of the surface geology at Tinker AFB; Wood and Burton (1968) extend the Fairmont Shale (Hennessey Group) over most of the Base, but Bingham and Moore (1975) map the Garber Sandstone over most of the Base and show the contact with the Fairmont Shale to lie, for the most part, south of S.E. 59th Street. Figure 2-5 is a shallow cross section across the southern portion of Tinker AFB, based on Phase IIB drilling. This cross section is supportive of the Wood and Burton (1968) map, in that it shows the Fairmont Shale occurring north of S.E. 59th St. However, no geologic mapping, per se, was done to support or refute either interpretation. In either event, the significant observations are the occurrence of shale and sandstone beds, whether they be Fairmont or Garber. Results of drilling are discussed further in Section 4.0.

Structure

Tinker AFB lies within a tectonically stable area. No major faults or fracture zones have been mapped near the base. Most of the consolidated rock units of the Oklahoma City area are nearly flat-lying. The reported regional dip is forty feet per mile in a generally westward direction (Bingham and Moore, 1975).

Ground Water

Shallow Aquifer - Shallow, ephemeral aquifers exist temporarily within the study area where zones of alluvium border streams or where shallow sandy residual soils collect precipitation. At Tinker AFB, sandy residual soils overlying bedrock at shallow depths form such an ephemeral aquifer. Soil aquifers are typically recharged directly by precipitation, gradually

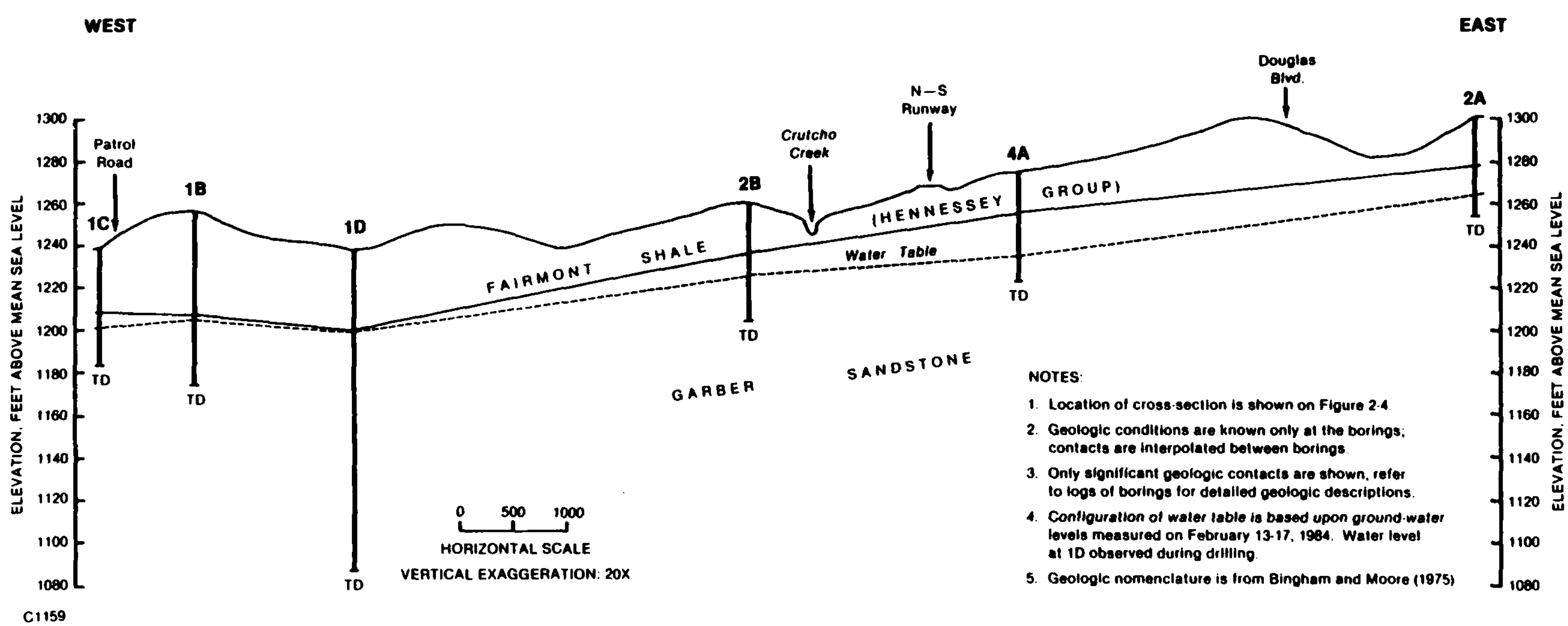

Figure 2-5. Shallow Geologic Cross-Section, Tinker AFB.

running dry seasonally as base flow to local streams and recharging of underlying rock aquifers deplete limited supplies. The significance of the shallow aquifer is that it may facilitate the contamination of important lower aquifers or surface waters by leachate generation and mobilization of wastes. It is not useable from a water-supply standpoint.

Garber-Wellington Aquifer - Tinker AFB lies within the limits of the Garber-Wellington Ground-Water Basin. The Garber Sandstone and the Wellington Formation are considered to be a single aquifer and provide the most significant source of ground-water supplies in the Oklahoma City area. At the present time, Tinker AFB derives most of its water supplies from this aquifer and supplements the supply by purchasing from the Oklahoma City Water Department. The nearby communities of Midwest City and Del City derive water supplies from both surface sources and wells tapping the aquifer. Industrial operations, individual homes, farm irrigation, and small communities not served by a municipal distribution systems also depend on the Garber-Wellington Aquifer. Communities presently depending upon surface supplies such as Oklahoma City also maintain a well system drilled into the Garber-Wellington as a standby source of water in the event of drought. The aquifer area is depicted in Figure 2-6.

The Garber Sandstone and the Wellington Formation are considered to be a single aquifer. They were deposited under similar conditions and consist of lenticular beds of sandstone, siltstone and shale that tend to vary in thickness over relatively short horizontal distances (Wood and Burton, 1968). The sediments constituting the aquifer tend to be loosely cemented and have a maximum thickness of some 1,000 feet. In the area of outcrop, ground water occurs under water table (unconfined) conditions and may occur at relatively shallow depths below ground surface (100 to 150 feet). In areas overlain by younger geologic units, ground water occurs in the aquifer under artesian (confined) conditions and wells must be drilled deeper (200-250 feet) in order to encounter it (Wickersham, 1979). Ground water can occur under either water table or artesian conditions in the vicinity of Tinker AFB.

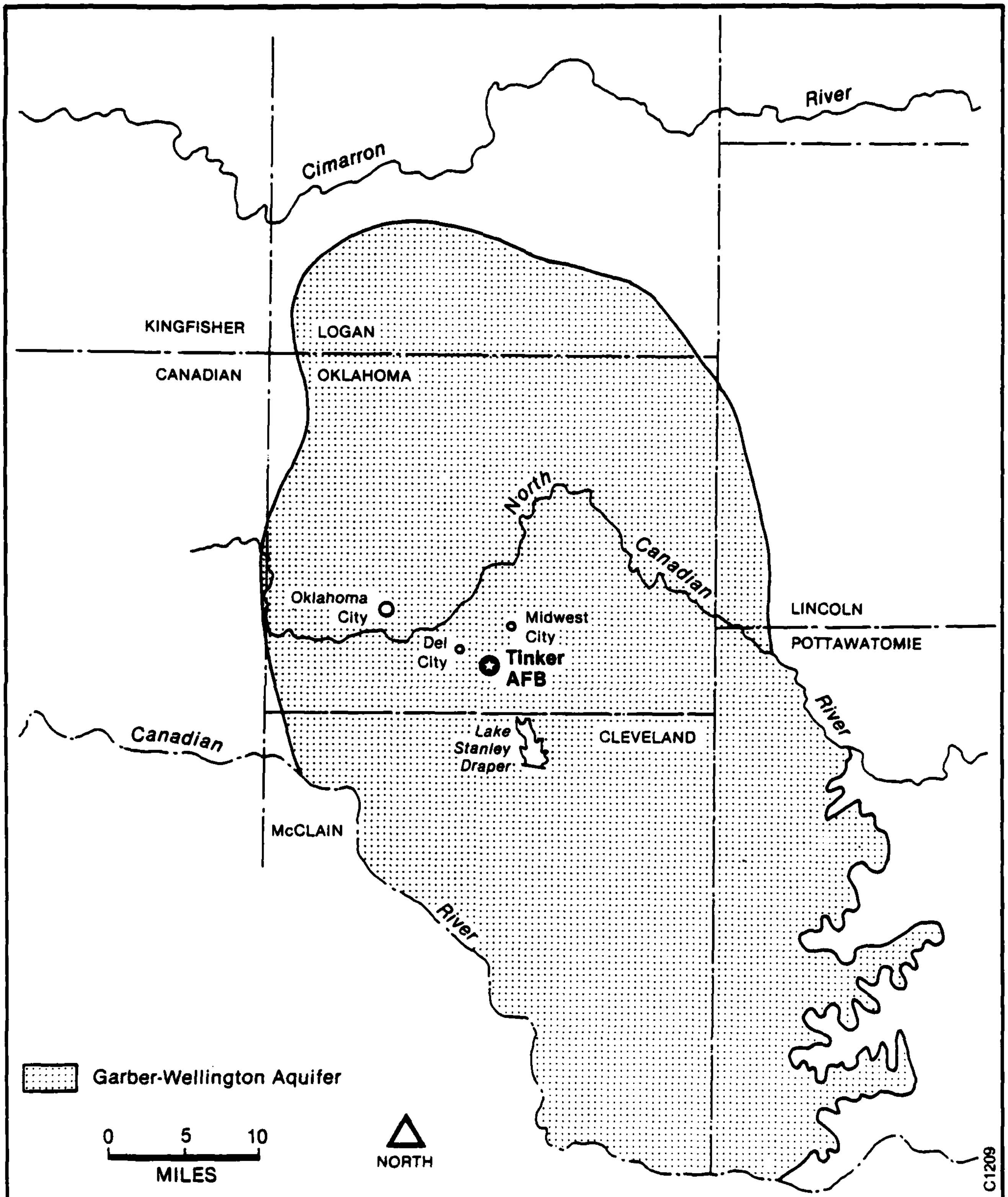

Figure 2-6. Location of Garber-Wellington Aquifer.

(Source: Marcher (1972); Wickersham (1979).

The Garber-Wellington aquifer is exposed at ground surface or mantled by a thin soil over the northern two-thirds of Tinker AFB. As noted above, the aquifer is probably overlain by a thin, discontinuous sequence of Hennessey Group sediments (Kingman Siltstone and Fairmont Shale) over the southern portion of the base. Water in useable quantities from productive zones in the Garber-Wellington is encountered at depths of approximately 100 feet at Tinker AFB, although the top of the saturated, but poorly productive, zone delineated by Phase II (Stage 1) drilling was usually less than 50 feet. A geologic cross-section of base wells developed by Wickersham (1979) is presented as Figure 2-7. This figure graphically depicts the lenticular nature of the sandy zones. Although most of the aquifer is believed to be saturated, multiple screened wells are usually constructed in order to obtain water from the more productive zones.

Recharge of the Garber-Wellington Aquifer is accomplished principally by rainfall infiltration and by percolation of surface waters crossing the area of outcrop. Because most of Tinker AFB is located in an aquifer outcrop area, it is therefore assumed that the base is situated in a recharge zone (Havens, 1981). The aquifer is therefore susceptible to contamination in the study area. Ground-water levels and flow directions (1976 data) are presented as Figure 2-8. It is important to note that Figure 2-8, a verbatim transcript from Wickersham (1979), is based on generalized data from throughout the area shown. It is "true" in only a regional sense. Results of detailed investigations in any one small portion of the area are likely to be at variance with the regional data. The maps show Tinker AFB to be within a roughly 10-mile long zone, trending northeast-southwest which makes up a regional ground-water "high" - i.e., a recharge zone. Superimposed on this is a local "low" or saddle surface, perhaps reflective of the ground-water withdrawals by the Base wells. According to the indicated hydraulic gradients, ground-water flow at Tinker AFB is presently directed to the west and northwest over most of the Base and to the south in the southeast part of the Base.

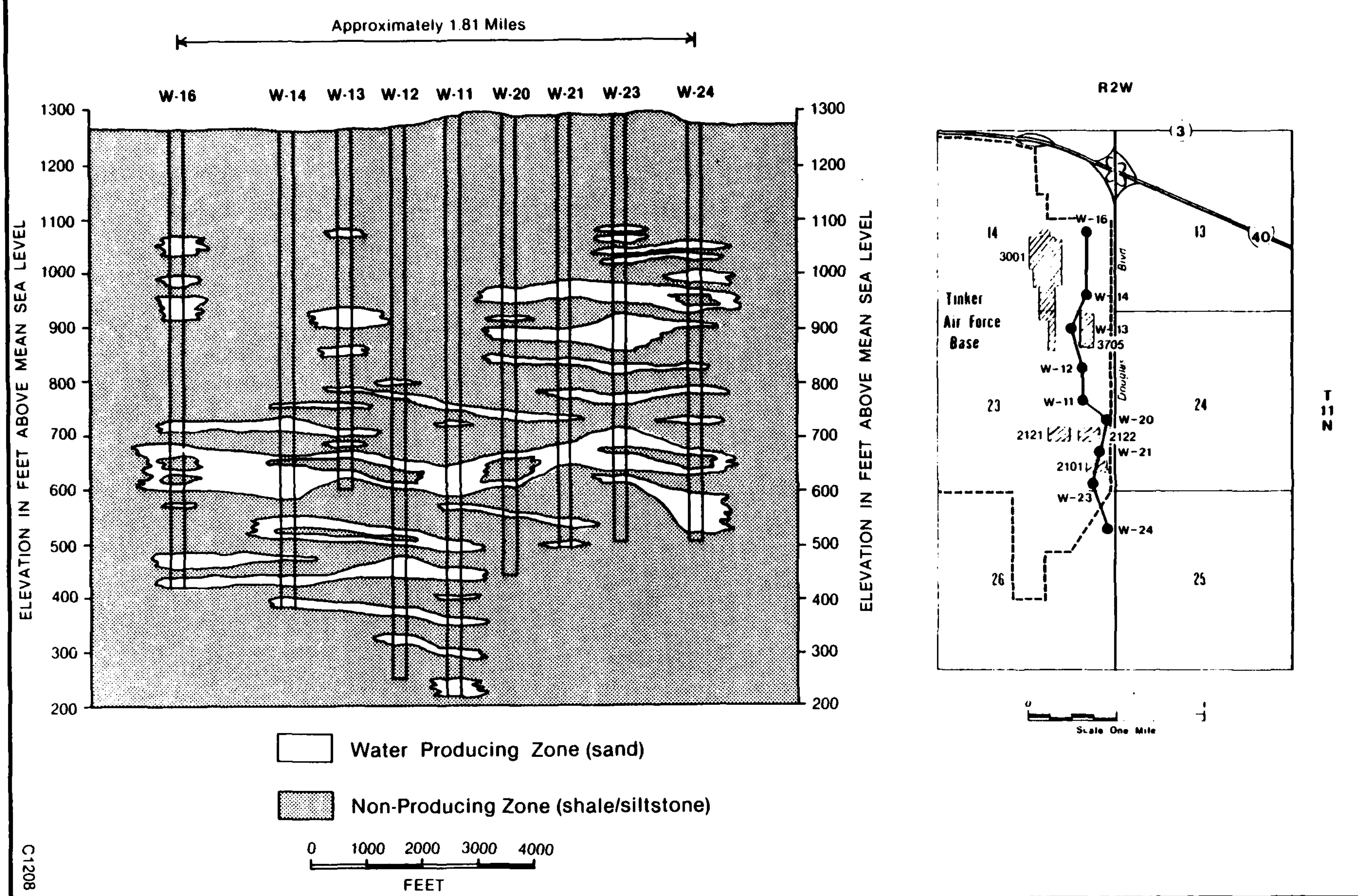

Figure 2-7. Geologic Section of the Garber-Wellington Aquifer at Tinker AFB (from Wickersham, 1979).

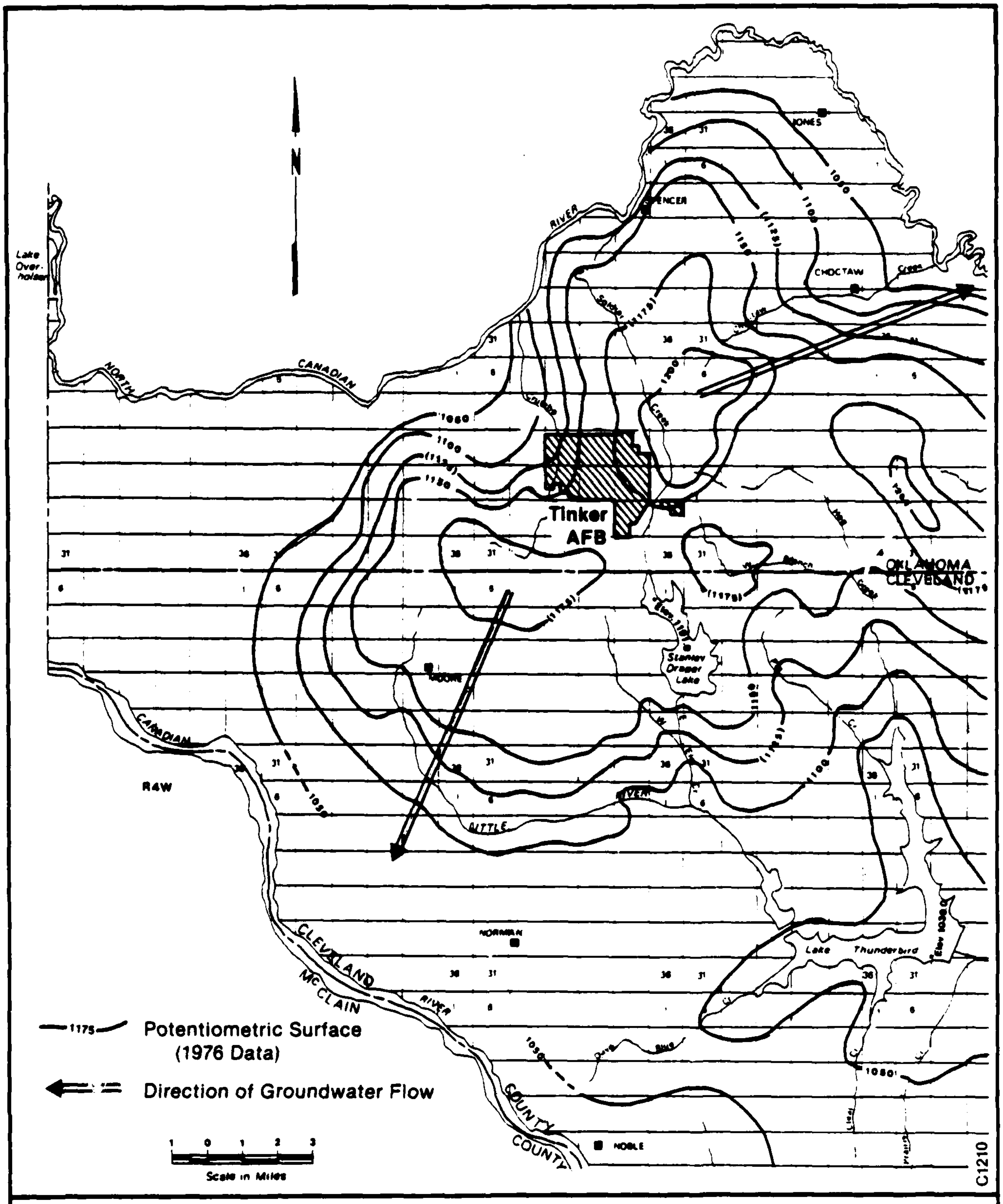

Figure 2-8. Ground-Water Levels and Flow Directions in the Garber-Wellington Aquifer (from Wickersham, 1979).

According to Wood and Burton (1968) and Wickersham (1979), the quality of ground water derived from the Garber-Wellington aquifer is generally good, although wide variations in the concentrations of some constituents such as hardness, sulfate, chloride, fluoride, nitrate, or dissolved solids, are known to occur. Wells drilled to excessive depths may encounter a saline zone, generally greater than 900 feet below ground surface.

2.4 Site Descriptions

Phase I studies for the Tinker AFB Installation Restoration Program were completed by Engineering Science in April 1982. The purpose of the Phase I study was to conduct a records search for the identification of past waste management activities which may have caused ground-water contamination and the migration of contaminants off-base.

Fourteen individual sites at Tinker AFB were identified as containing hazardous waste. The potential environmental consequence of each site was evaluated with a rating or scoring system. This system took into account such factors as the site environmental setting, the nature of the wastes present, past waste management practices and the potential for contaminant migration.

Of the 14 individual sites identified, eight sites, comprising four zones, were selected for Phase II studies. Two additional problem areas, not addressed in Phase I, were added to the list of sites for Phase II (Stage 1) studies. These are the Base water supply wells and the wells in Building 3001.

The general features of the sites evaluated in this study are discussed below as they are presented in the 1982 Phase I report. Detailed features of each site are discussed in Sections 3.0 and 4.0. The locations of each of the sites are illustrated in Figure 2-9.

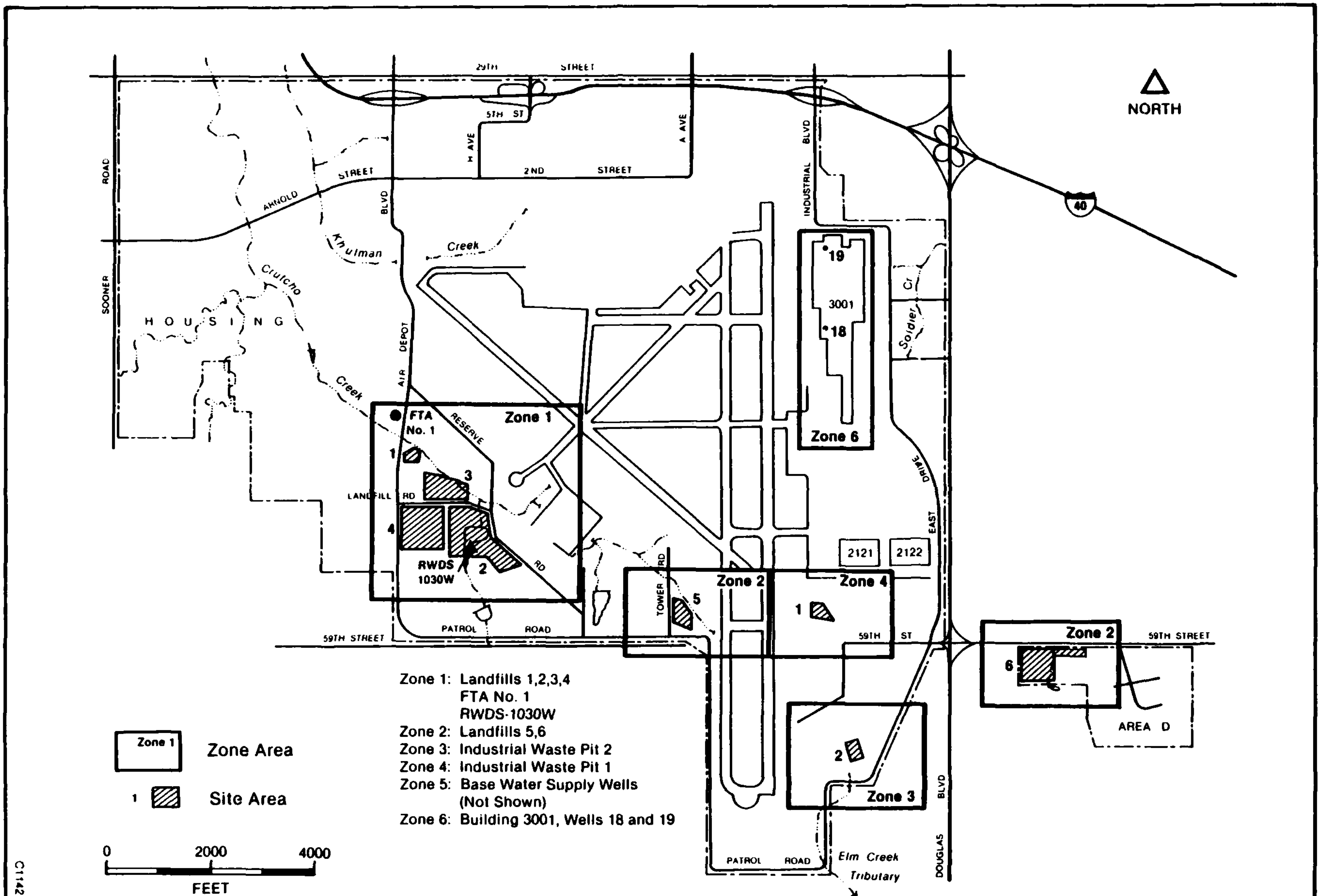

Figure 2-9. Zones of Investigation, Tinker AFB.

2.4.1 Landfills

Six landfills used for the disposal of refuse were identified at Tinker AFB. These landfills were grouped into two zones for the Phase II (Stage 1) study. Zone 1 consists of Landfills 1 through 4, and Zone 2 consists of Landfills 5 and 6. Five of the landfills are located on the base, and one is located on leased propety adjoining Area "D" east of the base.

Zone 1 - Landfill No. 1 is a small area, approximately 1 acre in size, south of Crutcho Creek along Air Depot Boulevard. This landfill was used from the start of operations at Tinker AFB in 1942 until 1945. Primarily general refuse (paper, household garbage, other non-industrial solid waste) from the base was disposed in the landfill, although the site may also have received waste solids from the domestic wastewater treatment plant. Refuse was disposed in trenches running east-west, and was typically burned to to reduce volume. The trenches extended to a depth of 10 to 25 feet, through a 6 to 8 foot clay layer into a sand/rock zone. Landfill No. 1 is well covered and shows no exposure of the disposal cells; however, settlement in the trenches has resulted in surface depressions where water collects from rainfalls. This water evaporates or percolates through the landfill.

After closure of Landfill No. 1, Landfill No. 2 was opened south of Landfill Road and west of Reserve Road. This landfill was utilized from 1945 until its closure in 1952. Approximately 20 acres were filled during this time period. Although most of the waste disposed of consisted of general refuse from the base, small quantities of paints and solvents were also buried. The waste was disposed of in trenches approximately 20 feet in depth and 35 to 40 feet wide, in an east-west orientation. The refuse was covered daily with several inches of excavated material, and completed trenches were covered with 3 to 4 feet of material.

Landfill No. 2 is well covered and vegetated with grasses and shows no erosion or exposure of landfill material. Several surface depressions with collected rain water caused by material settlement in the trenches are evident on the landfill. A pond, several acres in area, is also located on Landfill

No. 2. The pond was constructed in the mid-1960s either partly on top or adjacent to the landfill area. From the air, the outlines of trenches can be seen along the boundary of the pond where the water level is high enough to inundate portions of the trenches. Overflow from the pond enters the upper reaches of Crutcho Creek. It is presently unknown to what extent the pond waters percolate through the landfilled material.

During the time period 1952-1961, wastes were disposed of in an eight acre area designated as Landfill No. 3. This area is located adjacent to Landfill No. 2 north of Landfill Road and south of Crutcho Creek. Crutcho Creek crosses the northeast corner of Landfill No. 3. The type of waste disposed of and disposal methods were similar to previous landfills. The landfilled material consisted primarily of general refuse, but did include paint buckets, insecticide cans, and empty barrels. A number of vacuum tubes which contained low levels of radioactivity were also disposed of at this site. Landfill materials were disposed of in trenches running the length of the landfill. Trenches were approximately 25 feet deep, and extended through a surface clay layer into a sand/rock layer. The refuse was covered daily, and a final cover of 3 to 4 feet of excavated material was placed on completed trenches.

Additional radioactive material was reported to have been disposed of in a deep pit adjacent to the northwest corner of landfill No. 3. The area was formerly posted with radioactivity warning signs, which have been destroyed.

Landfill No. 3 shows no evidence of erosion along the creek or elsewhere around the landfill. At present, additional dirt and hardfill are being stored on top of the landfill. This practice has been in effect for approximately 5 years.

After closure of the Landfill No. 3, a 16-acre site south of Landfill Road between Landfill No. 2 and Air Depot Boulevard was utilized for

refuse disposal and designated Landfill No. 4. Disposal practices were essentially the same as previous landfills, with a daily cover of 3 to 6 inches of compacted excavated material applied to the refuse and a final cover of several feet of soil used for completed trenches. The landfill was closed in 1968.

Surface leachate and associated gases have been observed along the west slope of the landfill along Air Depot Boulevard on several occasions since closure. A major problem with leachate from the west bank of landfill No. 4 occurred during 1979. Unusually heavy rainfall occurred during that year. Leachate occurred in a drainage ditch eventually leading to Crutcho Creek. Leachate and drainage ditch wastewater samples analysis data indicated high concentrations of COD, oil and grease, phenols, and heavy metals. Unusually high concentrations of mercury (Hg) were also found in the leachate and drainage ditch samples, indicating that significant hazardous wastes quantities may be present in Landfill No. 4.

Although the landfill area was covered with a layer of top soil, small discharges of leachate are still observeable along the west and north of Landfill No. 4. Surface runoff from these areas, including leachate, enters the drainage ditch and eventually enters Crutcho Creek.

Also included in Zone 1 are Fire Training Area (FTA) No. 1 and Radiological Waste Disposal Site (RWDS) 1030W. FTA No. 1, in use from approximately 1950 to 1962, consisted of an unlined, diked area where fuel oil and unknown waste materials were ignited and extinguished. RWDS-1030W consisted of a pit in which radium final wastes (rags and acetone solutions which contained radium) were buried. A verbal report referenced in an Air Force document asserts that all radioactive wastes were removed in 1955 when the sanitary landfill was established (Engineering-Science, 1982).

<u>Zone 2</u> - Landfill No. 5 located north of Patrol Road and east of Tower Road, was used during the period 1968-1970. The disposal practices and types of wastes were the same as at Landfill No. 4. The three acre site is well covered and no waste material is exposed; however, waste compaction in

the trenches has resulted in surface depressions which collect and hold rain water. A small area of seepage is noticeable on the northeastern edge of the landfill adjacent to West Crutcho Creek. Recent (1984) construction activities have disrupted a portion of the landfill surface.

Landfill No. 6 was used for the disposal of refuse from 1970 to 1979. This landfill is located in Area "D" approximately 1/2 mile east of Tinker AFB along S.E. 59th Street on land leased from Oklahoma City. Although 40 acres are available at the site, only about 20 acres on the western half of the landfill were used prior to the closing of the site during 1979. Base refuse since that time has been disposed of off-site by private contractor.

Materials disposed in Landfill No. 6 consisted primarily of general refuse with small quantities of industrial waste materials such as paint buckets, insecticide cans, etc. Industrial wastewater treatment plant sludge was also intermittently disposed of in this landfill. The refuse was covered daily with 6 to 8 inches of compacted soil, and several feet of compacted cover was used as a final trench covering. Highly permeable river sand was used for daily cover for several years, although other areas had a cover of excavated clay and sand/rock. After closure, the site was revegetated with grasses. Field reconnaissance of the site indicated moderate surface erosion and no observed leachate.

2.4.2 Waste Disposal Pits

Prior to the establishment in 1963 of an industrial wastewater collection and treatment system, some of the industrial wastes were disposed of in large, open pits. Two waste disposal pit areas were located on the east side of the base south of the aircraft maintenance area. The pits were used for the disposal of industrial wastes between 1947 and 1965.

Industrial Waste Pit No. 1 (Zone Four of the Phase II (Stage 1) study) was located southwest of Building 2121. Waste disposal occurred during the period 1947-1958. During the Base records search, no written information

was located to indicate what was placed in the pit, although interviews with several base personnel indicated large quantities (i.e., more than 85 55-gallon drums) of waste oils, contaminated fuels, chromates, phenols, cyanides, and waste acids and bases generated by plating and maintenance activities were disposed in this facility. The petroleum based contents of the pit may have been burned routinely (Engineering-Science, 1982).

The pit was unlined, and unknown quantities of wastes may have migrated through the soil beneath and around the pit. Surface runoff from the No. 1 pit, if any, would have entered the headwaters of Crutcho Creek. Waste residue may still be present at the site, as there is no evidence that the pit was dredged to remove residual material when the pit was covered and graded over in 1958. There are no visible surface features to indicate exactly where Industrial Waste Pit No. 1 was located.

In 1958, Industral Waste Pit No. 1 was abandoned and a second pit (Industrial Waste Pit No. 2, Zone Three of the Phase II (Stage 1) Study), was constructed on a hill between Patrol Road and the airfield runway. Industrial Waste Pit No. 2 also received hazardous wastes such as waste oils, cyanides, chromates, phenols, solvents, and waste acids and alkalies. During the records search, no information was found concerning the construction of the pit. If the pit were unlined, hazardous wastes may have migrated beyond the original pit area. Aerial photographs (circa 1960) reveal that the waste pit may have had an overflow discharge which drained into Elm Creek, an intermittent stream. Disposal of hazardous wastes in the pit continued until the early 1960s, and the pit was filled and graded in 1965. There was no information indicating that the waste pit was dredged before it was covered.

2.4.3 Additional Water Supply Well Studies

In addition to the waste disposal site investigations (Zones 1 through 4) described above, the Phase II (Stage 1) studies also encompassed evaluation of Base water supply wells, as described below.

Zone 5 (Base Water Supply Wells)

Zone 5 consists of the 27 Base Water Supply Wells, a system of wells located along the east and west Base boundaries. All wells are completed in the Garber-Wellington Aquifer. Base Wells range from 700 to 900 feet in depth, with yields ranging from 205 to 250 gallons per minute. The wells incorporate multiple screens, deriving water supplies from sand zones that vary in thickness from 103 to 184 feet (Wickersham, 1979).

Zone 6 (Building 3001 Wells)

Zone six consists of two Base water supply wells (Wells 18 and 19) located within Building 3001 (The Oklahoma City Air Logistics Center manufacturing complex) in the northeast portion of the Base (Figure 2-9). An Air Force monitoring program had discovered both trichloroethylene (TCE) and tetrachloroethylene in these wells, so both were taken out of service. Radian was tasked with a preliminary assessment of the contamination in these wells.

Both Wells 18 and 19 are deep (>1,000 feet), high capacity water supply wells, pumping directly into the distribution system, which supplies both industrial and potable uses. The wells were drilled in 1942 and incomplete construction records remain. No driller's or geophysical logs were available, but partial casing and perforation records were found.

3.0 FIELD PROGRAM

Various field activities were performed at Tinker Air Force Base in support of the IRP Phase II (Stage 1) investigation. The activities consisted of the completion of eleven deep and four shallow ground-water monitor wells, performance of two ground conductivity (electromagnetic) surveys, and soil coring of two waste sites. The periods of performance of the field activities were November 1983 and February-March 1984.

3.1 Field Techniques

The following paragraphs contain descriptions of the various field techniques used in the Tinker AFB Phase II investigation. These techniques included geophysical surveying, hollow-stem augering and air rotary drilling, monitor well installation, and soil and ground-water sampling.

3.1.1 Geophysical Surveying

Geophysical surveying was performed in order to accurately define the area of investigation at two buried industrial waste pits (Zone 3 - Industrial Waste Pit No. 2 and Zone 4 - Industrial Waste Pit No. 1). The two sites are currently vacant land; no surface remnants of the waste disposal facilities are visible. The geophysical technique selected for the investigation consisted of an electromagnetic survey using two devices: the Geonics EM31 and the EM34-3 ground conductivity sensors. Both ground conductivity sensors are designed for rapidly obtaining data over large areas. The meters employ magnetic dipoles or magnetic induction loops for transmission and reception of low-frequency electromagnetic waves. The effective depth sampled by the EM31 is 6 meters; the depth sampled by the EM34-3 depends on the coil separation and orientation, applied frequency, and to some extent on the conductivity profile of the subsurface (McNeill, 1980). Geophysicon, Inc., of Lakewood, Colorado, performed the ground conductivity surveys at Zones 3 and 4. Operating procedures and specifications of the EM31 and EM34-3 are provided in Appendix L.

The methods of investigation were identical at both zones: two base lines were surveyed at 50-foot intervals prior to the geophysical survey. The intersection of the base lines was established at the estimated center of the pit based on an evaluation of aerial photographs of the sites. The grid was surveyed as shown for both locations in Figures 3-1 and 3-2 by compass and measuring chain. Each point was marked with a labeled pin flag. The measure-ements made at each station were:

- Measurements made with the EM31 with vertical magnetic dipoles;
- Measurements made with the EM34-3 (10m) separation with horizontal magnetic dipoles; and
- Measurements made with the EM34-3 (20m) separation with horizontal magnetic dipoles.

Results of the geophysical investigation are discussed in Sections 4.2.3 and 4.2.4.

3.1.2 Drilling Techniques

Drilling and coring at Tinker AFB were accomplished using two techniques: air-rotary drilling for deep monitor wells, and hollow-stem augering for shallow exploratory borings and monitor wells. Each method was selected on the basis of the anticipated depth of completion, need for detailed control of sampling and water-level observations, and geologic conditions expected at various depths.

Air Rotary Drilling

The air rotary drilling was performed with either a Failing 1250 (November activities) or a Failing 1500 (February-March activities) truck-mounted rig. A 6-7/8 inch tricone bit was used to drill the bore hole to a

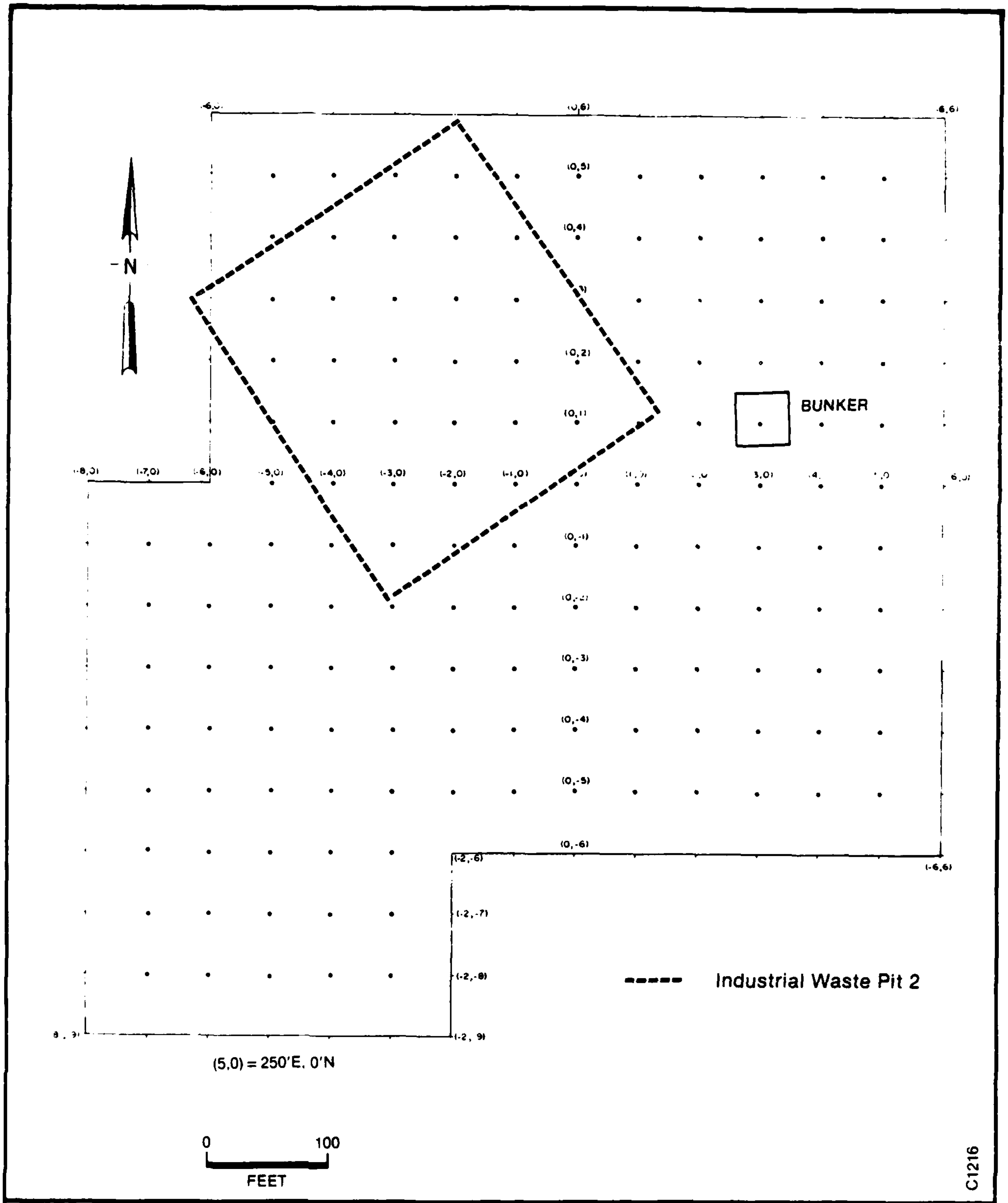

Figure 3-1. Data Point Grid for Geophysical Survey - Zone 3.

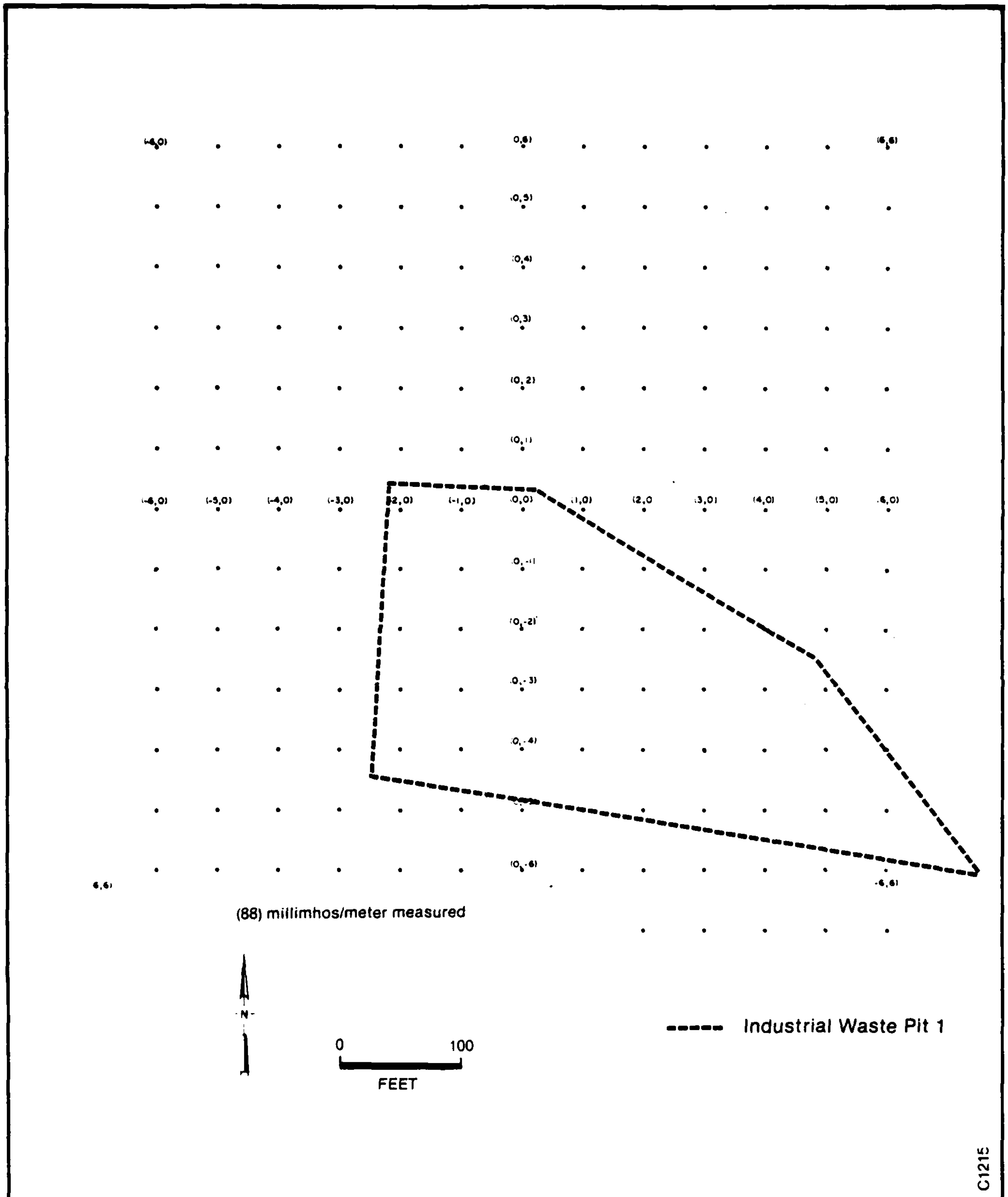

Figure 3-2. Data Point Grid for Geophysical Survey - Zone 4.

depth of 10 feet below the first ground water encountered. No drilling fluids or additives were used in the drilling program. As the bore hole was advanced, the cuttings discharged at the surface were examined for lithology, moisture, and other features to describe the geologic section. Drilling conditions, such as relative rate and ease of penetration, were noted by the driller. Water encountered during drilling was noted with respect to depth of occurrence and rate of production; if needed, drilling was suspended temporarily to allow for recovery of water in the borehole. The decision to complete the borehole and install the screen and casing for the monitor well was made on the basis of relative water level (with respect to the approximate predicted regional water level), the likelihood of perched water above a regional water table, and the representativeness of the water table in terms of evaluating the impact of the waste disposal site on the quality of ground water.

The method of introduction of contaminants is by dissolved constituents moving with downward migrating infiltration. Once these contaminants reach the ground-water body they are entrained in the flow and move with it. So long as no density effects operate, there will be no tendency for contaminants to plunge or sink in the ground-water system. Common causative agents of density effects, concentrated brines or nearly pure streams of dense industrial chemicals (such as TCE) do not exist at Tinker AFB, so this phenomena may safely be ignored. As was discussed in Section 2, there is a downward component of flow, so some contaminants would be expected to move down in the aquifer. However, they would also be diluted, so detection is less likely. Contaminants of interest are expected to be at their highest concentrations at the water table, so all wells were completed as near the water table as practicable.

Hollow-Stem Augering

A hollow-stem auger drilling rig, the Mobile B-50, was used at Zones 3 (Industrial Waste Pit 2) and 4 (Industrial Waste Pit 1) to perform shallow coring in the vicinity of the pits. The hollow-stem method allowed for an

accurate examination of soil conditions, identification of waste material and contaminated soil, and recovery of soil samples. The holes were drilled dry; no drilling fluids or additives were used. Samples of soil and waste were collected with a split-spoon sampler, a hollow tube driven in advance of the auger at regular intervals (ASTM D-1586). The samples were recovered at the surface, described in terms of lithology and moisture, and retained. Some difficulty was experienced in advancing the augers to the desired depth; the soil was stiff, making for slow penetration and refusal at shallow depth at some locations. Where refusal at shallow depths interrupted the planned exploratory program at Zone 3, the air-rotary rig was used to complete a bore hole for monitor well installation.

3.1.3 Monitor Well Installation

Ground-water monitor wells were installed immediately upon completion of the drilling operations. Usually, the borehole was observed for a period of time, as necessary, to determine the approximate static water level. Monitor well construction specifications, summarized in Table 3-1, were consistent with the specifications provided in the Statement of Work. Appropriate changes in the specifications were made on a site-by-site basis. Decisions regarding the setting of screen and casing, length of screen, and amount of gravel pack for each well were made on the basis of the observed static water level. If appropriate, the borehole was allowed to remain open overnight; there were no difficulties related to the integrity of the bore hole or caving problems.

Monitor well installation followed a similar procedure at each well. Screen and casing sections were cleaned and assembled on the ground then lowered carefully into the borehole. As the string of screen and casing were lowered, additional sections of casing were added until the bottom of the screen reached the complete depth of the borehole. Normally, enough casing was attached so as to leave a 3 to 5 foot stick-up at the ground surface. Clean gravel (grain-size analysis in Appendix D) was carefully poured down the annular space until the level of the top of the gravel pack was at least 2

TABLE 3-1. MONITOR WELL CONSTRUCTION SPECIFICATIONS

- Casing: 2-inch or 4-inch diameter, flush joint, Schedule 80 PVC.
- Screen: 2-inch or 4-inch diameter, flush joint, Schedule 80 PVC, 0.010-inch mill slot. Normal screen length was 10 feet, reduced to 5 feet at the discretion of the supervising geologist.
- Gravel pack: 8-12 mesh silica, emplaced from bottom of hole to 2 feet above top of screen.
- Bentonite seal: 2 feet above top of sand pack.
- Grout: neat cement (Type I Portland cement) grout from the top of the bentonite seal to the land surface.
- Surface completion: the PVC casing was cut off to provide a 2 to 3 foot stickup and solid cap placed on the casing. A 6-inch diameter guard pipe, 4 feet in length, was placed over the exposed casing, and seated in the cement. A locking cap lid was installed on the guard pipe.
- Guard pipes or posts: 3-inch diameter steel posts, 6 feet in length, with a minimum of 2 feet below ground, 3 each installed radially 4 feet from the wellhead.
- After each well was installed, it was developed by air lifting or bailing until a clear stream was produced, or until the supervising geologist determined that development was complete.
- The split-spoon sampler was washed between samples (water, acetone, water) and the drill pipe, bit, and augers cleaned (pressure water wash) between corings.

feet above the top of the screen, or as directed by the supervising geologist. (See individual well completion logs in Appendix D). Bentonite pellets were added to form a 2-foot thick seal, and if necessary for completion activities that occurred above the water table, water from the well was bailed and poured down the annular space to hydrate the bentonite. Neat cement grout was then prepared and tremied from the top of the bentonite seal to the land surface. The grout was allowed to cure for at least 24 hours prior to well development.

The monitor wells were developed by pumping using the air compressor on the drilling rig. The water in the casing was alternately purged and allowed to recover; this process generally took 4 to 6 hours. Individual records of the development of each well are included in Appendix D. After completion of the well development program, protective 6-inch diameter steel casing with lockable lids was cemented into place at the surface and three steel guard posts were positioned around the well.

In order to provide a basis for interpretation of chemical analysis results, a sample of the PVC well casing was tested for readily leachable organics. A 284 g section of 2-inch casing was immersed in 1450 mL of organic-free water and kept in glass at room temperature over a seven-day period. The resulting extract was analyzed for acid/neutral extractable organic priority pollutants by modified EPA Method 625. The only compound identified was isophorone (a solvent) at 3.7 μg/L. This test is not equivalent to the more aggressive leaching that could occur in contaminated ground-water, but does serve to identify casing which would have been a gross source of pollutants.

3.1.4 Ground-Water Sampling

Ground-water samples were collected for analysis from the 11 ground-water monitor wells installed under Phase II (Stage 1) (this program), eight previously existing ground-water monitor wells, and 20 base supply wells. Field sampling methodologies and equipment are detailed in the following sections.

Water Level Determination

As the first step of ground-water sampling operations at each monitor well, water level measurements were taken using a Soiltest Model 762A electrical probe. The probe and associated electrical line were washed with laboratory deionized water between each well to preclude the possibility of cross-contamination. Measurements were taken to the nearest 0.01 foot with respect to the top of the protective steel well casing. The elevation point was surveyed as discussed in Section 3.1.9. Water level measurements taken prior to each sampling operation are listed in Appendix E.

Water level measurements were not taken at the base supply wells since the readings would reflect levels influenced by pumping.

Well Purging

Following the completion of well construction activities, each monitor well was purged using a 1.75-inch diameter submersible gas-driven pump. The pump, manufactured by ISCO, Inc. (Model 2600) delivered water to the surface by means of the rapid inflation and deflation of the pump's silicone rubber bladder. Gas (compressed air from a cylinder) did not contact the sample; water comes into contact with stainless steel, polycarbonate, medical-grade silicone rubber, Teflon, polypropylene, Delrin acetal, polyethylene, and the PVC well casing. The pump was operated in the following way: after the pump was set at the appropriate position in the well, the gas supply and pump gas lines were attached to the control box, controls were adjusted to compensate for the bladder inflation rate at varying lifts and gas supply pressure, and the gas valves were opened to begin operation of the pump. Some of the eight existing monitor wells were purged and sampled with a 1.1 liter bottom-discharge Teflon bailer due to low water or poor yields.

Each well was purged either immediately prior to sample collection or within 1 day of sample collection (for low-yield wells) to ensure that fresh formation water was collected as the sample. Purging operations were conducted using a 1.1 liter bottom-discharge Teflon bailer. Purging operations were considered complete when 3 wetted well volumes had been evacuated.

All down-hole equipment used during the purging of the monitor wells was carefully washed with laboratory deionized water to prevent cross-contamination. In the case where overt contamination, as evidenced by color, odor, viscosity or visible oil, was noted in a well, the sampling apparatus was washed with technical-grade acetone and thoroughly rinsed with deionized water.

Specific conductivity and temperature were determined in the field using a conductivity and temperature meter. Temperature readings were checked using a mercury-in-glass thermometer. The pH of the discharged water was measured with the use of a pH meter. Prior to each pH measurement, the instrument was calibrated against standard solutions for pH values of 7.0 and 4.0 or 10.0. Prior to exposure to discharge water, the probe was thoroughly washed with deionized water.

Sample Capture

After each well was purged of standing water to ensure representative ground-water characteristics, a sample was collected and split into the analytical aliquots required by the Statement of Work. Samples from wells were collected for the analyses shown in Table 3-2.

In addition, acid/neutral extractable organic priority pollutant (GC/MS) analyses (modified EPA 625) were performed on 5 wells from Zone 1, 2 wells from Zone 2, 3 wells and 1 soil from Zone 3, 2 wells and 1 soil from Zone 4, and 5 wells from Zone 5. Volatile organic priority pollutant (GC/MS) analyses (EPA Method 624) were performed on samples of water from 5 wells from Zone 5.

The types of containers used for sample collection and the preservation techniques used are summarized in Table 3-3. All aspects of the sampling protocol were conducted in accordance with EPA-approved methodologies. Field QA/QC measures were employed to ensure that once collected, sample integrity was maintained during shipping and handling prior to analyses. These QA/QC procedures are discussed in Appendix F.

TABLE 3-2. ANALYTICAL SCHEDULE, TINKER AFB

Parameter	Zones
Barium	2
Iron	1, 2
Manganese	1
Total Organic Halogen (TOX)	1, 2, 3, 4
Oil and Grease	1, 2, 3, 4
Total Organic Carbon (TOC)	1, 2, 3, 4
Cyanide	1, 2, 3, 4
Metals (Cd, Cr, Ni, Cu, Zn, Pb, Hg)	1, 2, 3, 4
Volatile Hydrocarbons (EPA 601)	5
Total Phenol	1, 2, 3, 4
Pesticides and Herbicides	1, 2
Trichloroethylene and tetrachloroethylene (EPA 601)	6

TABLE 3-3. SAMPLE COLLECTION SUMMARY

Analytical Parameter(s)	Sample Container	Preservation	Volume
Chloride nitrate and TDS	Plastic bottle	4°C	500 ml
TOC	Glass bottle	4°C; H_2SO_4 to pH<2	250 ml
Cyanide	Plastic bottle	4°C; NaOH to pH>12	500 ml
Metals	Plastic bottle	HNO_3 to pH<2	500 ml
Volatile organics (EPA 601/624)	Glass vial with Teflon septa	4°C	40 ml
Phenolics	Glass bottle	4°C; H_2SO_4 to pH<2	1000 ml
Organic Priority Pollutants (EPA 625)	Glass bottle with Teflon-lined cap	4°C	1000 ml
Oil and Grease	Wide mouth glass jar with Teflon-lined lid	4°C; H_2SO_4 to pH<2	750 ml

A representative of the Oklahoma State Department of Health accompanied the Radian team during most of the sampling effort and split samples from selected monitor wells. A report of all available State data is provided in Appendix H. Analytical results are discussed in Section 4.0.

3.1.5 Geologic Sampling

Geologic sampling consisted of two distinct activities. The first consisted of the routine collection of samples from the air rotary discharge during well drilling. Geologic samples were collected at variable intervals during monitor drilling or where significant changes in lithology occurred. At coring operations (Zones 3 and 4), samples were collected through hollow-stem augers with the use of split-spoon sampler in accordance with ASTM Method D-1586. Grab samples from shallow depths were collected from the auger flights where conditions warranted. All split-spoon samples collected were described, logged, and placed in glass jars with screw-on lids. These samples were labeled and retained by Radian for future reference. Selected samples (ten each from Zones 3 and 4) were frozen and submitted for chemical analysis.

3.1.6 Sampling Schedule

A total of 38 wells were sampled for ground water during Phase II (Stage 1) field activities (February-March 1984). Generally, sufficient sample was obtained during a single sampling round to satisfy the volume requirements for all analytical tests to be performed. However, in some cases, well recovery or leachate production was very slow and sample sets from the same sampling point were collected on more than one occasion. Details of the sampling schedule, including well identification, sample type, date collected, date delivered to the laboratory, and sampler are provided in Appendices E and G.

3.1.7 Other Sampling

In addition to the monitor well sampling, selected surface water samples were also collected. Leachate seeps were sampled by excavating a small trench at the site of the seep and allowing water to accumulate. The surface impoundment at Landfill 2 was sampled by compositing grab samples from four randomly selected locations within the pond. Samples were submitted for the same chemical analyses as were the ground-water samples. An aliquot of the composited pond sample was also provided to the Base Bioenvironmental Engineering staff for radiochemical analysis.

3.1.8 Field Safety

Before the field work was initiated, a field Safety Plan was drawn up. This plan, developed from available data, anticipated likely field hazards and prescribed appropriate personal protective equipment for the field team. Drilling, core sampling and well installation within or in close proximity to the waste sites were expected to pose the most significant potential hazards. EPA Level C protection (impervious clothing, gloves, boots and full-face cartridge respirators) was required for drilling and well installation activities. For the ground-water sampling activities, EPA Level D protection (same as Level C, except that respirators were carried, but not worn) was deemed appropriate. The Safety Plan was followed for the complete field effort, and provided adequate protection. The complete text of the Safety Plan utilized for this project is contained in Appendix M.

3.1.9 Surveying

After all wells were installed, wellhead elevations for Zone 1 were determined to the nearest 0.01 foot, by surveying from the nearest benchmark. The Base Civil Engineering Squadron surveying section accomplished this work. The report of the base surveyors is contained in Appendix E.

3.2 Zone Activities

The field program at Tinker AFB consisted primarily of the installation and sampling of ground-water monitor wells. Other activities, such as geophysical surveying, soil coring and sampling, and leachate and pond sampling, were also conducted. The conduct of the field program is presented in narrative form in the following subsections. For each of the zones of investigation, a similar sequence of events was followed, as described in Section 3.1. Each zone of investigation (Figure 3-3) is discussed separately, below.

3.2.1 Zone 1 (Landfills 1 through 4)

This section contains a description of the field activities that occurred at Zone 1, consisting of Landfills 1 through 4. Zone 1 is located at the southwest corner of Tinker AFB; bordered by Patrol Road on the west, Crutcho Creek on the northeast, and Storage Road area on the south. The activities that took place at Zone 1 included: completion of 4 boreholes, installation of 3 ground-water monitor wells, sampling of a series of existing ground-water monitor wells near Crutcho Creek, sampling of the newly-installed monitor wells, and sampling of the leachate from Landfill 4 and water from the recreational pond.

Monitor Well Installation

The locations of the drilling sites are illustrated on Figure 3-4. These locations were selected in order to provide complete coverage of the hydrogeologic conditions at Zone 1. The anticipated ground-water flow direction was to the west and southwest. Well 1A, located on the northwest portion of the zone, is the shallowest boring; borehole 1D, located east of the zone, was intentionally drilled as the deepest boring for the purpose of investigating the subsurface to at least 150 feet below the land surface. Wells 1B and 1C, south and west of the zone, respectively, were drilled to intermediate depths. Each boring encountered a weathered zone of residual soil, underlain

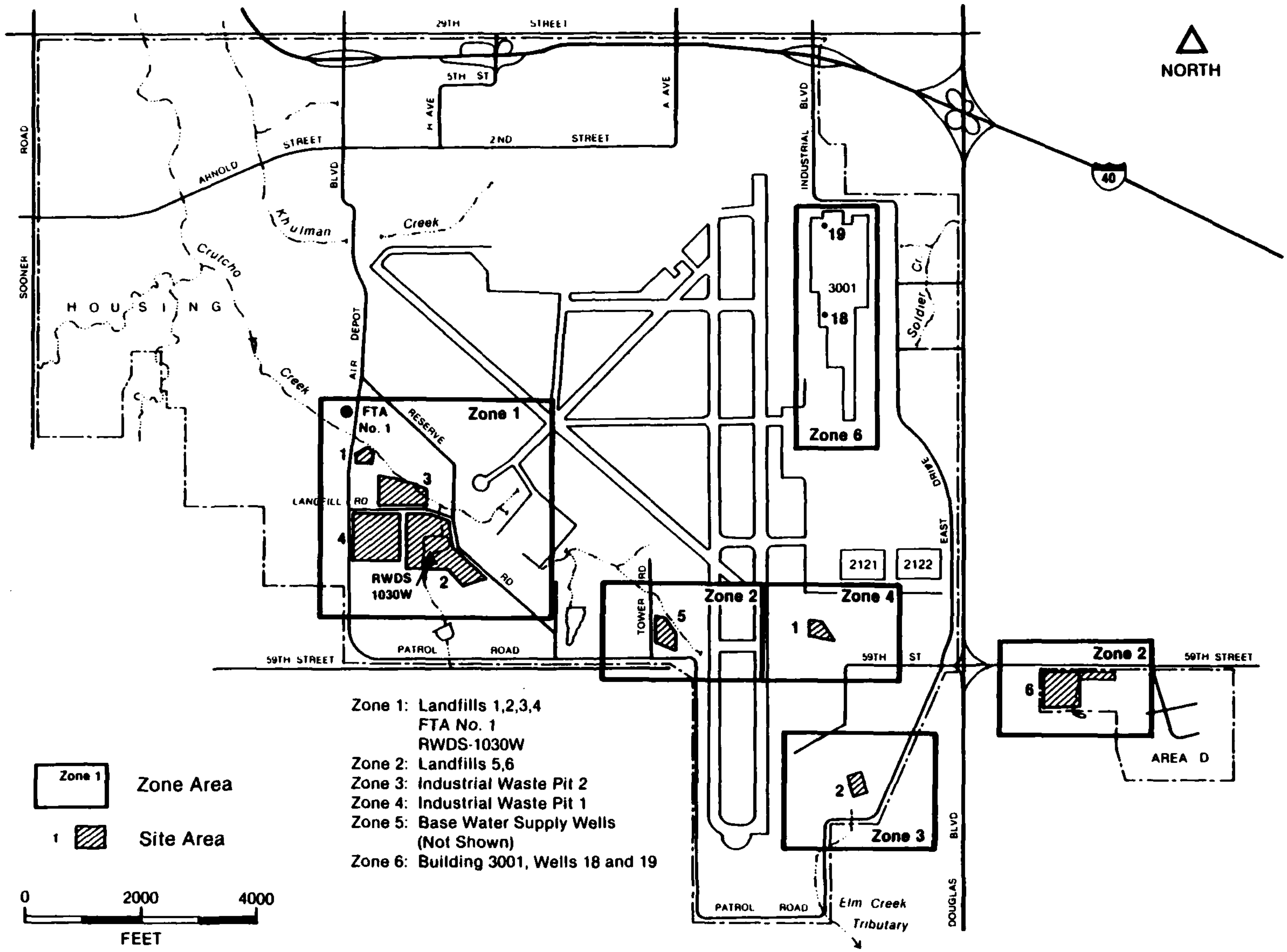

Figure 3-3. Zones of Investigation, Tinker AFB.

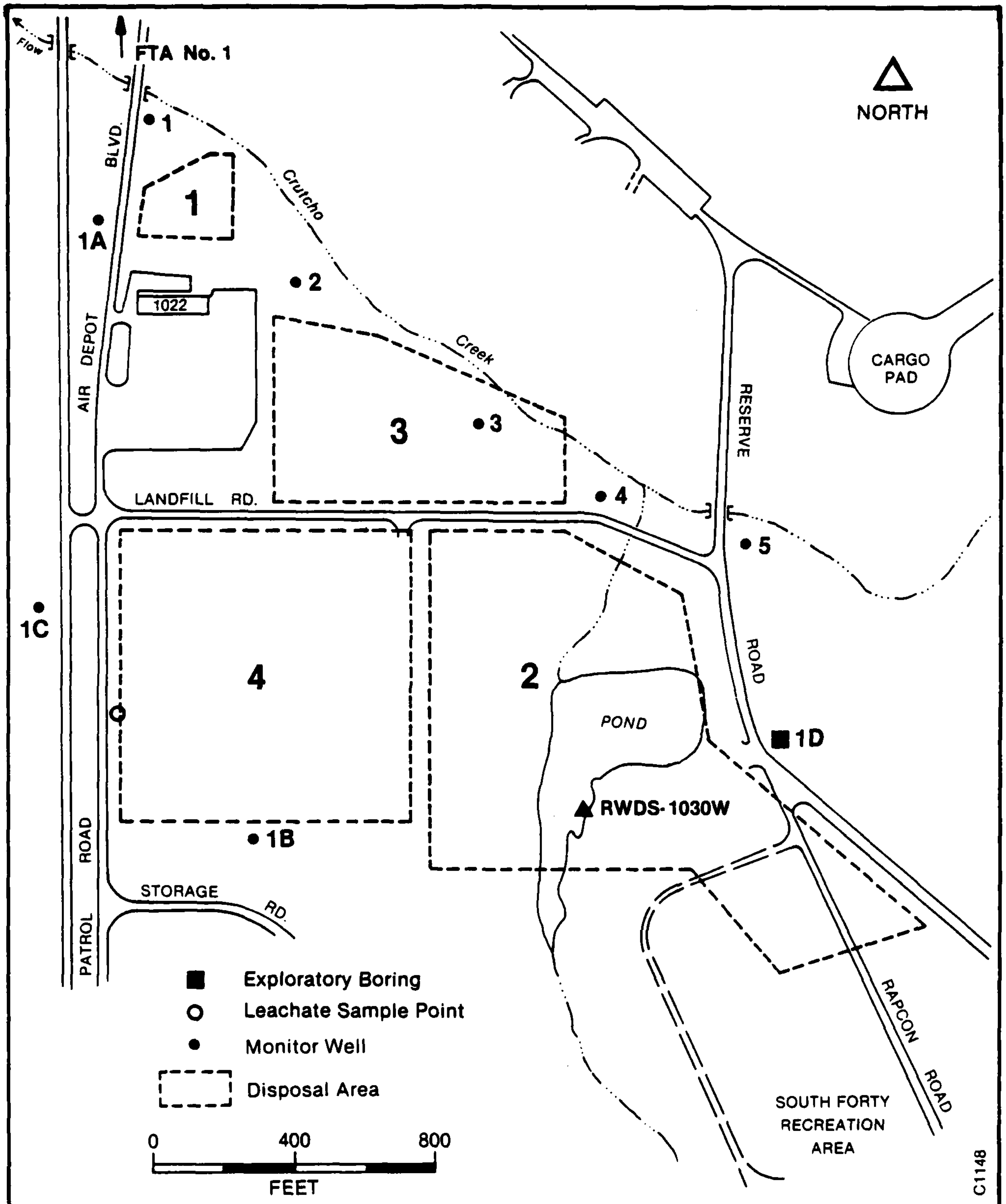

Figure 3-4. Drilling Locations - Zone 1.

by predominantly shale and siltstone, in turn underlain by sandstone. Results of the drilling program at 1D revealed that the production of water increased with increasing depth below the land surface. Appendix D contains detailed descriptions of the logs of borings and well completion data. Table 3-4 provides a summary of monitor well and test hole data.

After the completion of the monitor wells, samples of ground water were collected from each of the newly-installed wells and the existing wells along Crutcho Creek.

Monitor Well Sampling

After the completion and initial development of the monitor wells, each one was purged and sampled. Existing monitor wells were also purged prior to sampling. Field sampling was conducted by Radian personnel during the period 12-18 February 1984. Details of the field sampling procedures are presented in Section 3.1.4. The ground-water samples were analyzed for the parameters as shown on Table 3-5. Results of Zone 1 analyses are discussed in Section 4.2.1.

Other Sampling

In addition to the monitor well sampling, surface water samples were also collected for analysis for the same parameters. A leachate seep on the west face of Landfill 4 was sampled by excavating a small trench and allowing water to accumulate. Historical leachate seeps at the other landfills remained dry throughout the period and could not be sampled. The pond at Landfill 2 was sampled by compositing grab samples from four randomly selected locations within the pond. An aliquot of the composited sample was provided to the Base Bioenviromental Engineering staff for radiochemical analysis.

TABLE 3-4. GENERAL SPECIFICATIONS FOR ZONE 1 MONITOR WELLS AND CORES

Monitor Well or Core	Measuring Point Elevation[1]	Measuring Point Height	Ground Level Elevation[2]	Screened Interval[3]	Screen Elevations[4]	Total Depth[5]
1A	1223.09	3.00	1220.09	25-35	1195-1185	35
1B	1256.03	2.58	1253.44	65-75	1191-1181	75
1C	1242.49	2.91	1239.59	45-55	1197-1187	55
1D	1238[7]	0	1238[7]	grouted	N/A	150
1[6]	1219.16	2.90	1216.26	37.8-41.8	1178-1174	42.8
2	1222.09	2.95	1219.14	35.8-39.8	1183-1179	42.6
3	1223.37	2.58	1220.79	28.0-32.0	1193-1189	34.3
4	1225.10	3.25	1221.85	29.0-32.5	1193-1189	41.9
5	1227.78	2.95	1224.83	24.0-29.0	1201-1196	32.2
6	1243.63	2.95	1240.68	24.4-28.4	1216-1212	32.2
7	1247.63	2.66	1244.97	18.5-22.5	1226-1222	25.8
8	1254[7]	2.54	1251[7]	16.2-20.2	1235-1231	22.9

[1] Top of PVC casing for monitor wells; ground level for cores; surveyed, except as noted.
[2] Feet, msl to nearest 0.1 foot.
[3] Feet below ground level.
[4] Feet, msl.
[5] Feet below ground level.
[6] Wells 1-8, pre-existing monitor wells.
[7] Ground level elevations taken from Base topographic map.

TABLE 3-5. ANALYTICAL SCHEDULE, ZONE 1

Cadmium
Cyanide, total
Chromium
Copper
Iron
Herbicides
  2,4-D
  2,4-5TP (Silvex)
Mercury
Manganese
Nickel
Oil and Grease (IR)
Lead
Pesticides (EPA Method 608)
  DDT Isomers
  aldrin
  dieldrin
  lindane
  methoxychlor
  heptachlor
  heptachlor epoxide
Total Organic Carbon
Total Organic Halogen
Total Phenol
Zinc
Acid/Neutral Extractable Organic Priority Pllutants
 (modified EPA Method 625)[1]

[1] Radian-installed monitor wells and two selected existing monitor wells, only.

3.2.2 Zone 2 (Landfills 5 and 6)

Zone 2 consisted of two widely-separated landfills: Landfill 5 west of the main runway and southwest of Crutcho Creek, and Landfill 6 east of Tinker AFB and south of S.E. 59th Street near Area "D". These landfills represent the most recent on-base landfilling operations, with the period of activity ranging from 1970 to 1979. Earlier ground-water investigations at these sites have resulted in the placement of monitor wells near Crutcho Creek at Landfill 5 and near an unnamed tributary of Soldier Creek near Landfill 6 along S.E. 59th Street.

Monitor Well Installation

Drilling for the emplacement of monitor wells at Zone 2 was conducted from 17 to 20 November 1983. Two wells were installed; 2A at Landfill 6, and 2B at Landfill 5. Both wells were installed in boreholes drilled using the air rotary method. Locations of the wells are shown on Figures 3-5 and 3-6. Prevailing ground-water flow was determined to be generally south on the basis of published information (Figure 2-8) (Wichersham, 1979). Therefore, well 2A was located on the south margin of Landfill 6 in order to monitor conditions hydraulically downgradient from the landfill. Regional ground-water flow in the vicinity of Landfill 5 is believed to be to the south or southwest; well 2B was therefore placed on the south side of Landfill 5 to monitor downgradient conditions and provide complementary coverage to the existing 3 monitor wells located to the north and east of the landfill. Appendix D contains detailed descriptions of the log of borings and well completion data. Table 3-6 provides a summary of monitor well data.

Monitor Well Sampling

After the completion and initial development of the monitor wells each one was purged and sampled. Field sampling was conducted by Radian personnel during the period 12-18 February 1984. Details of the field sampling procedures are presented in Section 3.1.4. The ground-water samples were analyzed for the parameters specified in the Statement of Work as shown on Table 3-7. Results of all analyses are discussed in Section 4.2.2.

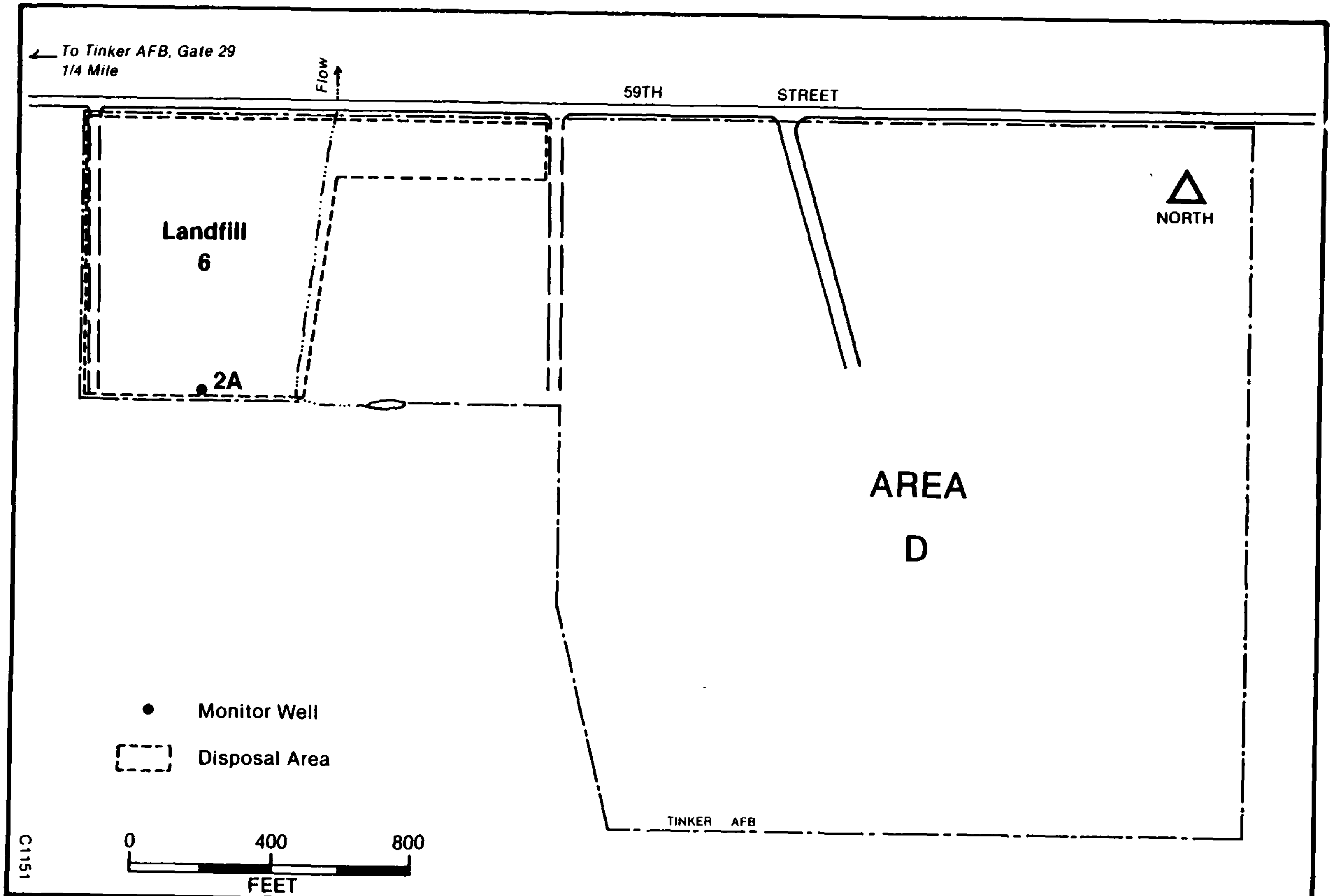

Figure 3-5. Location of Well 2A - Zone 2, Landfill 6.

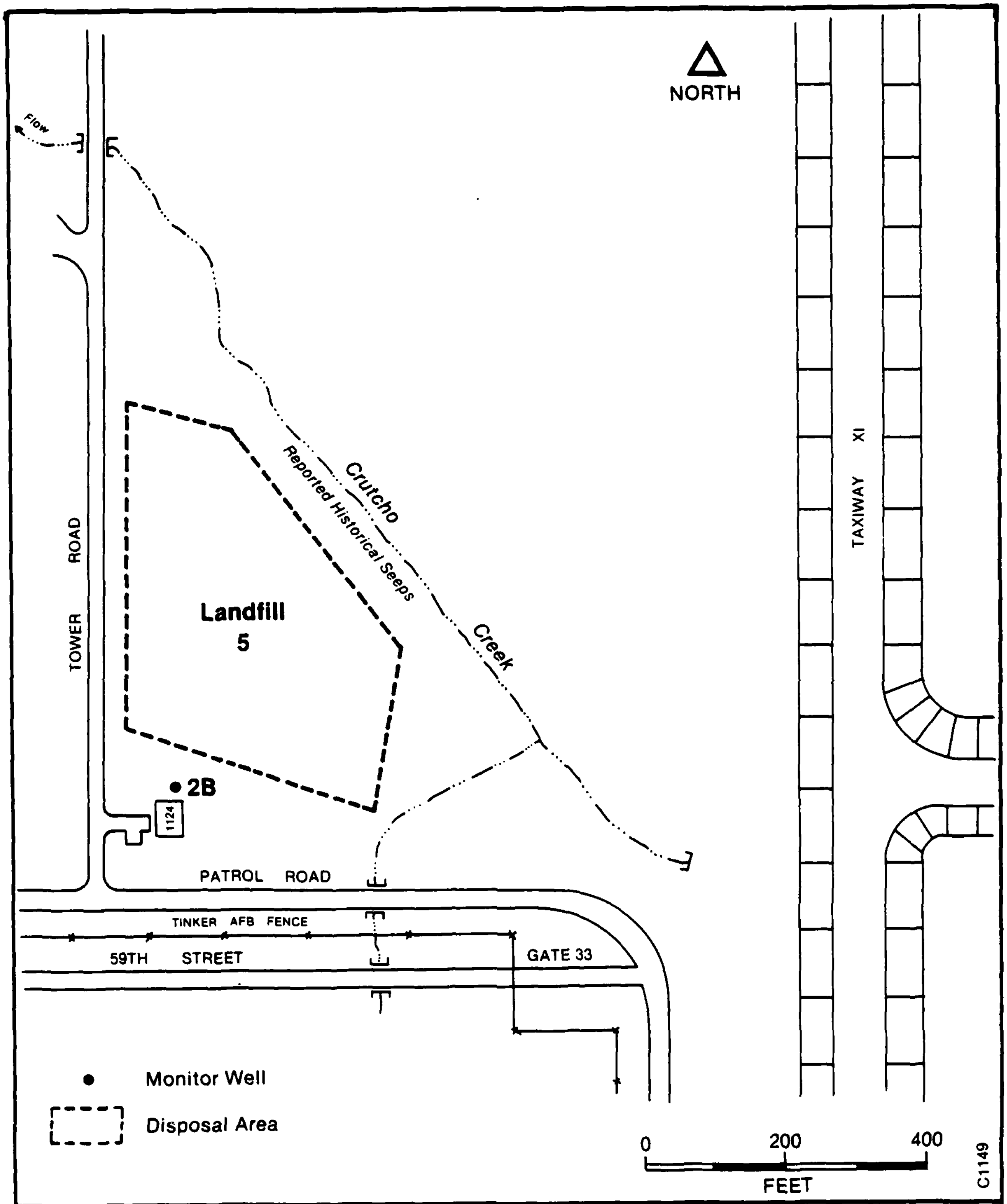

Figure 3-6. Location of Well 2B - Zone 2, Landfill 5.

TABLE 3-6. GENERAL SPECIFICATIONS FOR ZONE 2 MONITOR WELLS

Monitor Well	Measuring Point Elevation[1,2]	Measuring Point Height	Ground Level Elevation[2]	Screened Interval[3]	Screen Elevations[4]	Total Depth[5]
2A	1297.7	2.70	1295	35.5-45.5	1259.5-1249.5	45.5
2B	1257.6	2.60	1255	45.0-55.0	1212.6-1202.6	55

[1]Top of PVC casing for monitor wells; ground level for cores.
[2]Feet, msl taken from Base topographic map.
[3]Feet below ground level.
[4]Feet, msl.
[5]Feet below ground level.

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TABLE 3-7. ANALYTICAL SCHEDULE, ZONE 2

Barium
Cadmium
Cyanide, total
Chromium
Copper
Iron
Herbicides
2,4-D
2,4-5TP (Silvex)
Mercury
Nickel
Oil and Grease (IR)
Lead
Pesticides (EPA Method 608)
DDT Isomers
aldrin
dieldrin
lindane
methoxychlor
heptachlor
heptachlor epoxide
Total Organic Carbon
Total Organic Halogen
Total Phenol
Zinc
Acid/Neutral Extractable Organic Priority Pollutants (modified EPA Method 625)

Leachate Sampling

Historically, a leachate seep existed at Landfill 5. However, this seep was not in existence during the sampling period and so could not be sampled. The surface of the landfill had been disrupted by construction activities. This situation, coupled with low rainfall, may have caused the seep to be temporarily dry.

3.2.3 Zone 3 (Industrial Waste Pit No. 2)

Zone 3 is located on the southeast corner of Tinker AFB, just west of Douglas Boulevard (Figure 3-7). The site was formerly used as Industrial Waste Pit No. 2, which received a variety of liquid and solid wastes during the period 1958-1965 (see a complete description of the site under Section 1.4). Two major field activities took place at Zone 3: a geophysical survey to determine the precise location and extent of the buried pit, and a coring and well installation program to provide direct observations on the subsurface conditions at the site.

Geophysical Survey

The geophysical survey consisted of a complete ground conductivity (electromagnetic EM) survey conducted with reference to two perpendicular base lines having an origin at the estimated center of the former pit. Complete details of the procedures and equipment used in the survey are discussed in Section 3.1.1. The EM survey location, including the grid points from which the survey was performed, is illustrated on Figure 3-1.

Monitor Well Installation

Three ground-water monitor wells were installed at Zone 3; two "shallow" wells and one "deep" well. The deep well was located and constructed in a manner similar to the wells installed at Zones 1 and 2. The prevailing regional ground-water flow, believed to be to the southwest

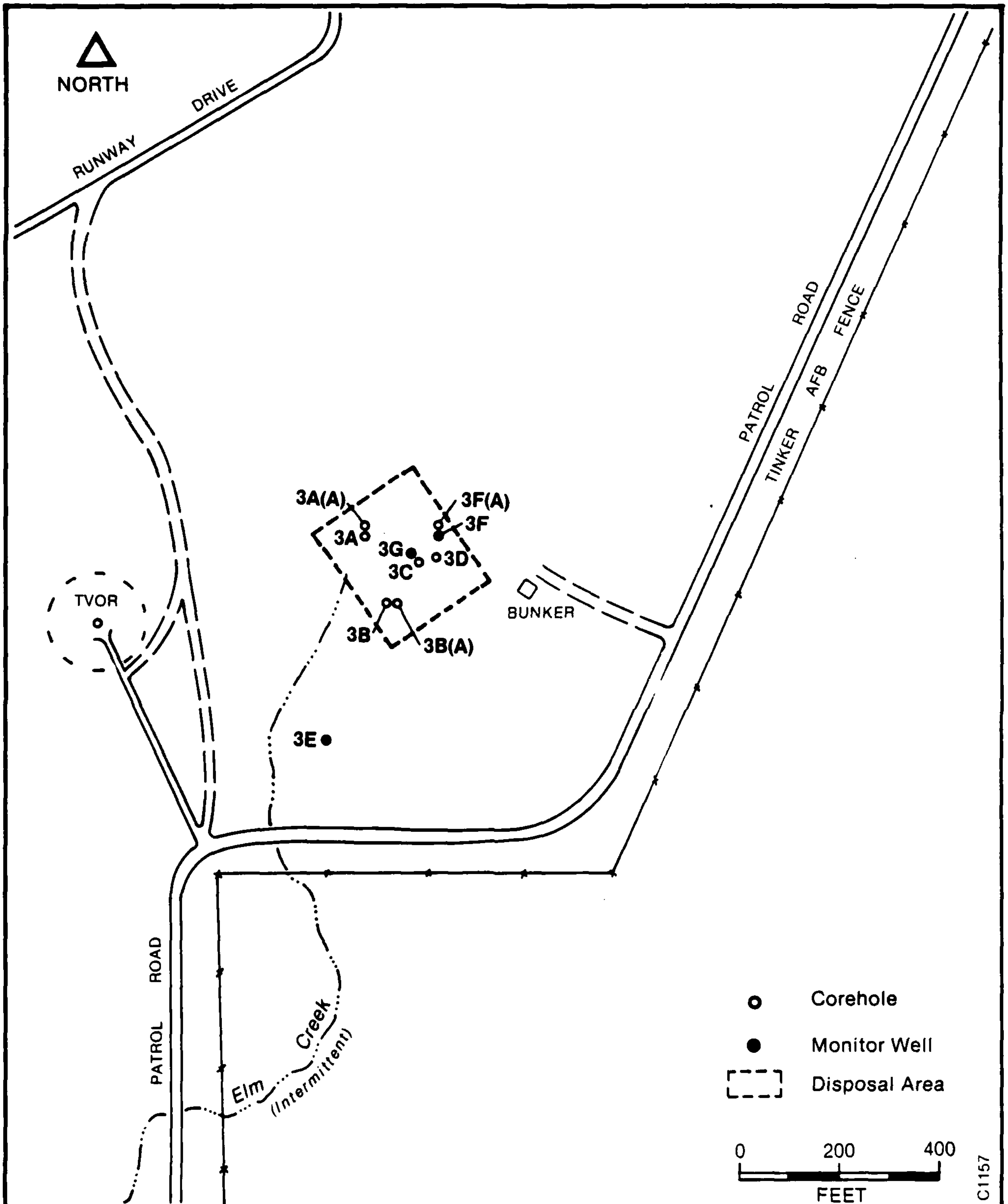

Figure 3-7. Drilling Locations, Zone 3 - Industrial Waste Pit No. 2.

(Wickersham, 1979), was used as the primary criterion for the location of the well (Figure 2-8). The borehole for the well (Well 3E) was advanced using the air rotary method; the well was completed at a depth consistent with well depths at other zones in order to monitor the first significant occurrence of ground water. The shallow wells (Wells 3F and 3G) were installed in boreholes drilled using hollow-stem auger equipment as part of the effort to define subsurface conditions directly beneath the buried industrial waste pit. In total, 8 boreholes (some duplicate boreholes where refusal was shallow) were drilled using the hollow-stem auger, revealing a wide range of subsurface conditions in a relatively small area. Small diameter wells (consisting of 2-inch PVC as described in Section 3.1) were installed in the two boreholes that collected amounts of water judged to be significant. In some cases, the boreholes were allowed to remain open over a period of several days in order to observe the inflow of water. Appendix D contains detailed descriptions of the logs of borings and well completion data. Table 3-8 provides a summary of the cores and monitor well data.

Soil Sampling

During the coring operations, samples were collected through the hollow-stem augers with the use of split-spoon sampler in accordance with ASTM Method D-1586. All split-spoon samples collected were described, logged, and containerized in glass jars with screw-on lids. These samples were labeled and retained by Radian for future reference. Where samples were lost in sampling (i.e., no sample was found when the split-spoon was withdrawn), a second boring was made adjacent to the first. Samples recovered from the second boring are identified as "alternate" samples. Ten selected samples were frozen and submitted for chemical analysis. Results of chemical analyses are discussed in Section 4.2.3.

Monitor Well Sampling

After the completion and initial development of the monitor wells, each one was purged and sampled. Field sampling was conducted by Radian

TABLE 3-8. GENERAL SPECIFICATIONS FOR ZONE 3 MONITOR WELLS AND CORES

Monitor Well or Core	Measuring Point Elevation[1,2]	Measuring Point Height	Ground Level Elevation[2]	Screened Interval[3]	Screen Elevations[4]	Total Depth[5]
3A	1305	0.0	1305	grouted	N/A	10
3A(A)[6]	1305	0.0	1305	grouted	N/A	5
3B	1303	0.0	1303	grouted	N/A	11
3B(A)[6]	1303	0.0	1303	grouted	N/A	21
3C	1305	0.0	1305	grouted	N/A	10
3D	1305	0.0	1305	grouted	N/A	10
3E	1297.6	2.6	1295	64.5-74.5	1230.5-2330.5	74.5
3F	1309.9	2.9	1307	15.4-30.3	1291.6-1276.6	30.4
3F(A)	1307	0.0	1307	grouted	N/A	6
3G	1302	2.3	1305	3.0-8.0	1302-1297	8.0

[1]Top of PVC casing for monitor wells; ground level for cores.
[2]Feet, msl taken from Base topographic map.
[3]Feet below ground level.
[4]Feet, msl.
[5]Feet below ground level.
[6](A) = alternate.

personnel during the period 12-18 February 1984. Details of the field sampling procedures are presented in Section 3.1.4. The ground-water samples were analyzed for the parameters specified in the Statement of Work as shown on Table 3-9. Results of all analyses are discussed in Section 4.2.3.

3.2.4 Zone 4 (Industrial Waste Pit No. 1)

Zone 4 is located on the east side of Tinker AFB, east of the main runway and south of Buildings 2121 and 1221, north of S.E. 59th Street (Figure 3-8). It is the former site of Industrial Waste Pit No. 1, which received a variety of liquid and solid wastes during the period 1955-1957 (see a complete description of the site under Section 1.4). Two major field activities took place at Zone 4: a geophysical survey to determine the precise location and extent of the buried pit, and a coring and well installation program to provide direct observations on the subsurface conditions at the site.

Geophysical Survey

The geophysical survey consisted of a complete electromagnetic (EM) survey conducted with reference to two perpendicular baselines having an origin at the estimated center of the former pit. Complete details of the procedures and equipment used in the survey are discussed in Section 3.1.1. The EM survey location, including the grid points from which the survey was performed, is illustrated on Figure 3-2.

Monitor Well Installation

Three ground-water monitor wells were installed at Zone 4; two "shallow" wells and one "deep" well. The deep well was located and constructed in a manner similar to the wells installed at Zones 1 and 2. The prevailing regional ground-water flow, believed to be to the southwest (Wickersham, 1979), was used as the primary criterion for the location of the well (Figure 2-8). The borehole for the deep well (Well 4A) was advanced using the air rotary method; the well was completed at a depth consistent with well depths

TABLE 3-9. ANALYTICAL SCHEDULE, ZONE 3

Cadmium
Cyanide, total
Chromium
Copper
Mercury
Nickel
Oil and Grease (IR)
Lead
Total Organic Carbon
Total Organic Halogen
Total Phenol
Zinc
Acid/Neutral Extractable Organic Priority Pollutants (modified EPA Method 625)[1]

[1]Ground-water samples and one selected soil sample only.

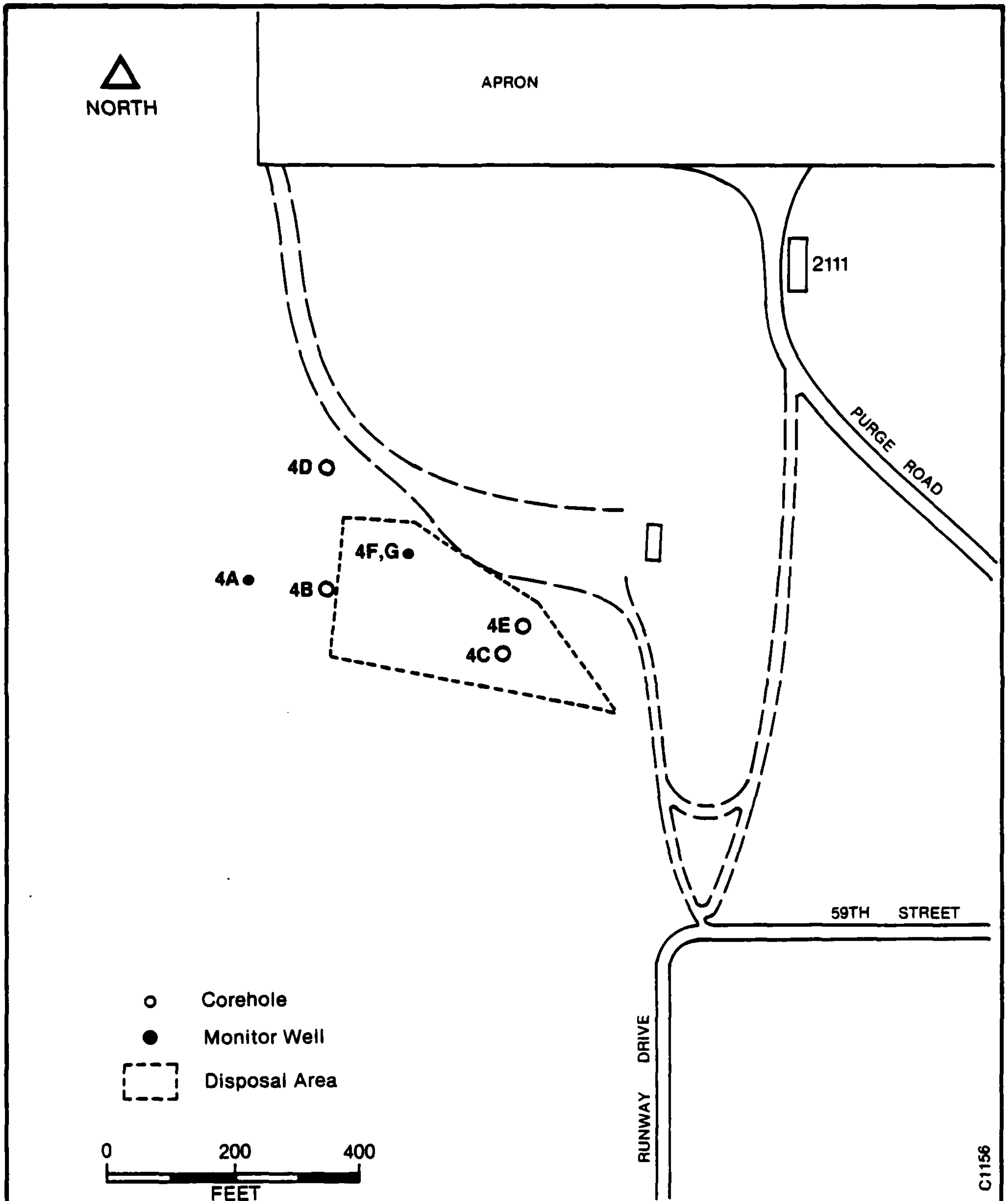

Figure 3-8. Zone 4 - Industrial Waste Pit No. 1.

at other zones in order to monitor the first significant occurrence of ground water. The shallow wells (Wells 4F and 4G) were installed in boreholes drilled using hollow-stem auger equipment as part of the effort to define subsurface conditions directly over the buried industrial waste pit. In total, six boreholes were drilled using the hollow-stem auger, revealing a wide range of subsurface conditions in a relatively small area. Small diameter wells (consisting of 2-inch PVC as described in Section 3.1) were installed in two adjacent boreholes. The shallow borehole (4G) collected a significant amount of water within a few hours; the deeper borehole (4F) remained dry but was converted to a monitor well in order to observe the possible accumulation of ground water in the shale bedrock. Appendix D contains detailed descriptions of the logs of borings and well completion data. Table 3-10 provides a summary of the cores and monitor well data.

Soil Sampling

During the coring operations, samples were collected through the hollow-stem augers with the use of split-spoon sampler in accordance with ASTM Method D-1586. All split-spoon samples collected were described, logged, and containerized in glass jars with Teflon-lined screw-on lids. These samples were labeled and retained by Radian for future reference. Ten selected samples were frozen and submitted for chemical analysis. Results of chemical analysis are discussed in Section 4.2.4.

Monitor Well Sampling

After the completion and initial development of the monitor wells each one was purged and sampled. Field sampling was conducted by Radian personnel during the period 12-18 February 1984. Details of the field sampling procedures are presented in Section 3.1.4. The ground-water samples were analyzed for the parameters specified in the Statement of Work as shown on Table 3-11. Results of all analyses are discussed in Section 4.2.4.

TABLE 3-10. GENERAL SPECIFICATIONS FOR ZONE 4 MONITOR WELLS AND CORES

Monitor Well or Core	Measuring Point Elevation[1,2]	Measuring Point Height	Ground Level Elevation[2]	Screened Interval[3]	Screen Elevations[4]	Total Depth[5]
4A	1275.20	2.2	1274	41-50	1232-1223	51.0
4F	1278	2.45	1275	5.75-15.75	1272.25-1262.25	15.75
4G	1276.90	1.95	1275	3.0-8.0	1272-1267	8.0
4B	1273	0.0	1273	grouted	N/A	20.0
4C	1273	0.0	1273	grouted	N/A	24.0
4D	1274	0.0	1274	grouted	N/A	22.0
4E	1273	0.0	1273	grouted	N/A	18.0

[1]Top of PVC casing for monitor wells; ground level for cores.
[2]Feet, msl taken from Base topographic map.
[3]Feet below ground level.
[4]Feet, msl.
[5]Feet below ground level.

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TABLE 3-11. PARAMETERS FOR WATER AND SOIL ANALYSES - ZONE 4

Cadmium
Cyanide, total
Chromium
Copper
Mercury
Nickel
Oil and Grease (IR)
Lead
Total Organic Carbon
Total Organic Halogen
Total Phenol
Zinc
Acid/Neutral Extractable Organic Priority Pollutants (modified EPA Method 625)[1]

[1]Ground-water samples and one selected soil sample only.

3.2.5 Zone 5 (Base Water Supply Wells)

Zone 5 consists of the 27 Base water supply wells, as shown on Figure 3-9. Each operational well (total of 20) was sampled during 7-17 February 1984. Samples were submitted to the laboratory for screening analyses (Total Organic Carbon and EPA Method 601). Based on the results of these tests, five samples were resubmitted for analyses by EPA Methods 624 (Volatile Organic Priority Pollutants by GC-MS) and modified 625 (Acid/Neutral Extractable Organic Priority Pollutants by GC-MS). Seven of the wells were not in service (electrical or mechanical malfunctions) at the time of sampling. At the close of the field season, none of these wells had been placed back in service, so no samples could be collected from them.

Most of the wells at Tinker AFB are in service at all times, in an automatic or demand-cycle mode (i.e., the pump motor starts when the pressure in the distribution system drops below a set point). Thus, most wells were periodically purged in normal service and extensive purging prior to sampling was not required. Each well was sampled in the same manner, as follows:

- o If the well was actually running when it was approached, sample bottles were prepared and the sample collected 3-5 minutes after arrival. Field pH, temperature and conductivity determinations were also made.

- o If a well was in service but not running when approached, the pump was turned on while the sample containers were prepared and field pH, temperature and conductivity determinations were made. Samples for analysis were collected after the well had been pumping for approximately five minutes.

- o If a well was not in service when approached, the pump was turned on and periodic samples taken for pH and conductivity. When these field parameters were unchanged between successive measurements, the well was deemed ready for sampling for analysis.

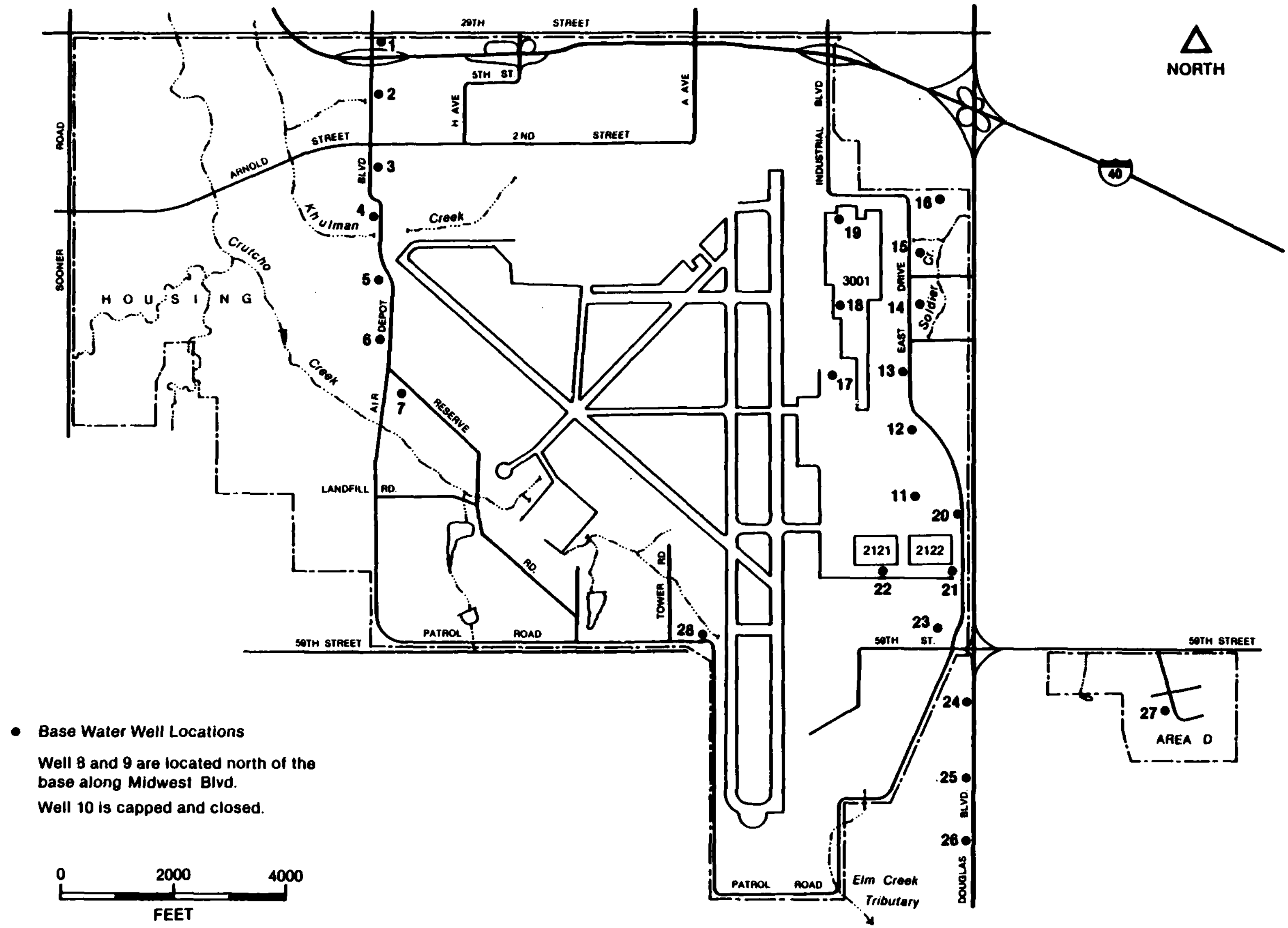

Figure 3-9. Zone 5 - Base Water Supply Wells.

- Certain wells could not be extensively pumped, either because of known contamination or hydraulic problems of unspecified nature in the distribution system. These wells were pumped for only five minutes, and samples collected without regard to observed pH or conductivity measurements.

The results of the chemical analyses are discussed in Section 4.2.5.

3.2.6 Zone 6 (Building 3001 Wells)

Zone six consists of two Base water supply wells (Wells 18 and 19) located within Building 3001 (The Oklahoma City Air Logistics Center manufacturing complex) in the northeast portion of the Base (Figure 3-10). An Air Force monitoring program had discovered both trichloroethylene (TCE) and tetrachloroethylene in these wells, so both were taken out of service. Radian was tasked with a preliminary assessment of the contamination in these wells.

Both wells 18 and 19 are deep (>1,000 feet), high capacity water supply wells, pumping directly into the distribution system, which supplies both industrial and potable uses. The wells were drilled in 1942 and incomplete construction records remain. No driller's or geophysical logs were available. Partial casing and perforation records were found. These records are summarized on Table 3-12.

The initial inspection revealed tht each wellhead is located in a permanent room, isolated from the manufacturing areas. Both rooms were clean and dry, displaying no evidence of industrial contamination. Thus, no source of TCE or other industrial compounds exists at the wellhead.

The issues to be addressed by the investigation were as follows, listed in order of priority:

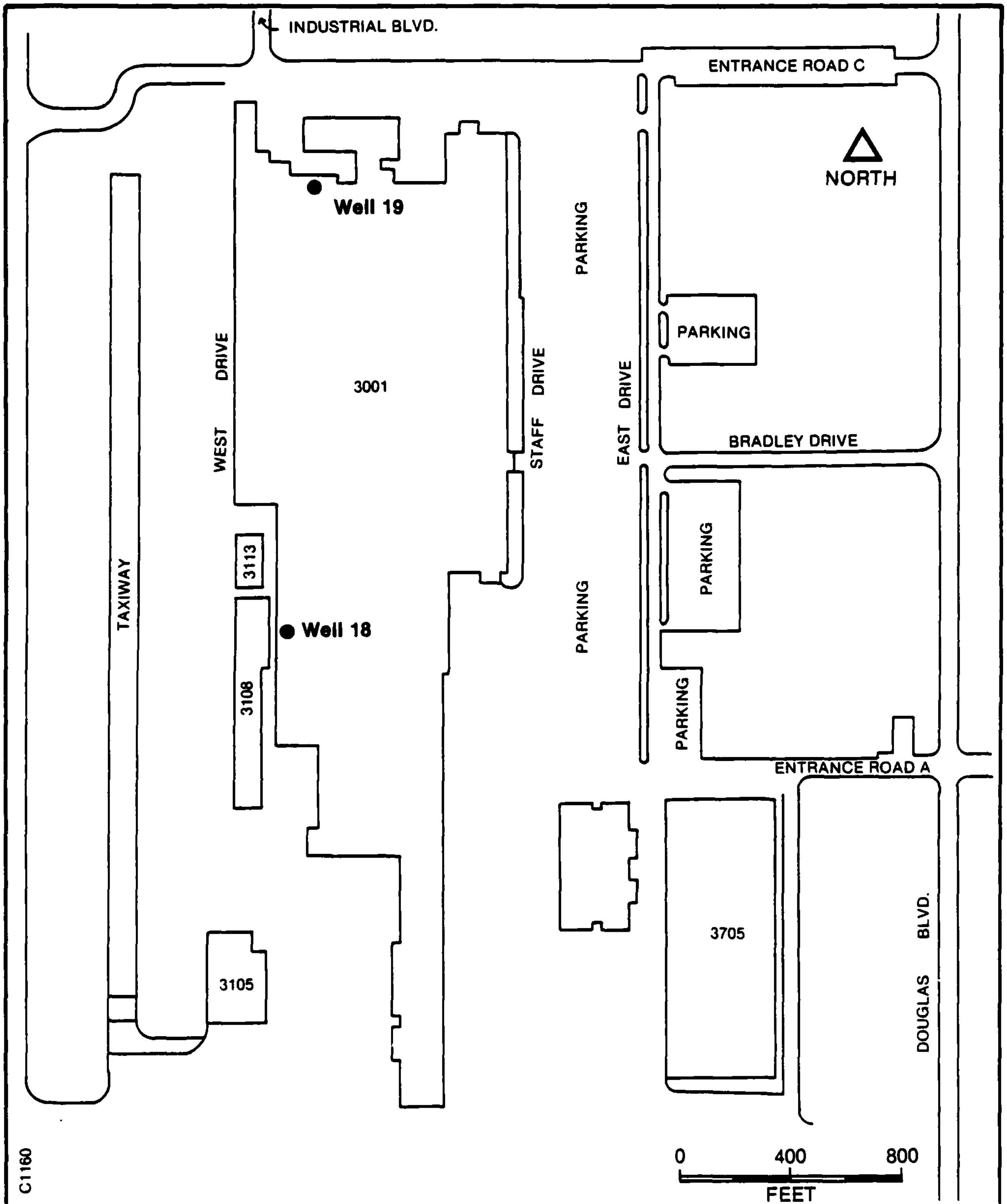

Figure 3-10. Zone 6 (Building 3001 Wells).

TABLE 3-12. CONSTRUCTION DATA, WELLS 18 AND 19

Well 18

Casing	Perforation Schedule
Surface Casing	No record
10 3/4" liner	577' to 607' 642' to 700'
7" liner	770' to 787' 806' to 834' 872' to 877'
5 1/2" liner	951' to 957' 1003' to 1017'

Well 19

Casing	Perforation Schedule
Surface Casing	No record
10 3/4" liner	548' to 645' 680' to 714'
7" liner	768' to 775' 851' to 872' 908' to 912' 948' to 961' 983' to 990'
5 1/2" liner	991' to 1002' 1029' to 1056'

- o Occurrence (i.e., quantity) of contaminants in the deeper aquifer.
- o Mechanism for introduction of contaminants into well bore.
- o Occurrence of contaminants in shallow zone.
- o Movement of contaminants in shallow zone.
- o Source of contaminants.

Radian determinated that the most effective means of addressing the highest priority issues was to conduct a protracted pump test with periodic sampling for contaminants of interest. If contaminants were shown to decline with continued pumping, this could be taken as evidence for limited contamination within the deeper zones of the aquifer. If, on the other hand, contaminant concentrations showed a constant or increasing trend, this would be evidence for widespread contamination. Corrollary issues (occurrence of contaminants in shallow zones, etc.) would be addressed after the results of the preliminary investigation were available.

The original plan, as specified in the modified Statement of Work, was to test-pump wells 18 and 19 for a period of up to eight hours each, collecting samples periodically for analysis by Method 601 for trichloroethylene (TCE) and tetrachloroethylene. However, as long as these wells remain connected to the water distribution system, neither could be pumped for more than approximately five minutes. Since test-pumping remained the method of investigation most likely to yield the required data in a timely and cost-effective manner, the method of investigation was modified. The test-pumping was limited to a single, 16-hour test of Well 18, only, which was disconnected from the distribution system with temporary plumbing installed to allow the well to discharge to the industrial sewer inside Buiding 3001. The test took place on 5 March 1984. Results are discussed in Section 4.2.6.

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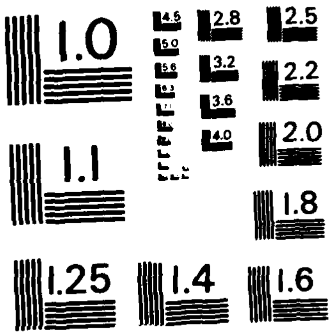

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4.0 DISCUSSION OF RESULTS AND SIGNIFICANCE OF FINDINGS

In this section, the hydrogeologic observations and chemical analytical data are discussed on a zone-by-zone basis. Hydrogeologic interpretations are made on the basis of the available data. Analytical chemistry data are discussed within the context of available regulatory standards and criteria. After an introduction section dealing with available standards and criteria, the discussion of results and significance of findings are each discussed zone by zone in separate sections.

4.1 Regulatory and Human Health Criteria and Standards

In order to determine possible water quality impacts on the local ground-water systems, the organic and inorganic compounds detected in the ground-water samples were compared to various criteria. These criteria were drawn from federal drinking water regulations, standards and guidelines. Table 4-1 shows parameters detected, along with the corresponding primary or secondary drinking water standard. These standards provide a stringent comparison for human health considerations.

The second column of Table 4-1 lists EPA toxicity values for chemicals detected. These human health criteria are also available for most of the other organic chemicals detected, as summarized on Table 4-2. Although these criteria do not have the force of standards, they do provide a valid means of assessing properties of chemicals of concern. Many of the compounds are proven or suspected animal carcinogens where zero consumption is recommended for the protection of human health. Many are also regulated as hazardous waste under RCRA (40 CFR Parts 262 and 263). For each zone, parameters detected are evaluated in comparison with these standards and criteria.

The use of human health criteria and standards for comparison of ground-water contamination at Tinker AFB provides stringent evaluations of observed concentrations. Since the shallowest zones of the aquifer are not used as water supply sources, contaminants in-situ have neither human health

TABLE 4-1. REGULATORY STANDARDS OR CRITERIA FOR GROUND-WATER ANALYSES

Parameter[1]	Federal Standard (mg/L)	EPA Toxicity[2]
Barium	1.0	
Cadmium (P)	0.010	
Chromium (P)	0.05	
Lead (P)	0.05	
Mercury (P)	0.002	
Copper (S)	1	
Iron (S)	0.3	
Manganese (S)	0.05	
Zinc (S)	5	
Phenols (Total)	-	3.5 ppm
Cyanide (Total)	-	200 ppb
Nickel	-	13.4 ppb

[1]Federal primary and secondary drinking water standards denoted by (P) and (S) respectively. Regulatory references: Federal Register 24 October 1980 and 7 September 1979.

[2]U.S. EPA estimate of safe levels of toxicants in drinking water for human health effects (Federal Register 28 November 1980).

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TABLE 4-2. GUIDELINES FOR ORGANIC COMPOUNDS DETECTED IN GROUND WATER

Compound	EPA Toxicity[1,2] ppb unless noted
<u>EPA Method 601</u> (Purgeable halocarbons)	
Methylene Chloride	0 (1.9)[3]
1,1-Dichloroethene	0 (0.33)
trans-1,2-Dichloroethene	n.c.[4]
1,1-Dichloroethane	0 (9.4)
1,2-Dichloroethane	0 (9.4)
1,1,1-Trichloroethane	18.4 ppm
Trichloroethylene	0 (27)
Chlorobenzene	488
Chloroform	0 (1.9)
Bromodichloromethane	0 (1.9)[3]
Tetrachloroethylene	0 (8)
<u>Modified EPA Method 625</u> (Acid/Neutrals)	
1,2-Dichlorobenzene	400
1,3-Dichlorobenzene	400
1,4-Dichlorobenzene	400
di-n-butyl phthalate	34 ppm
Isophorone	5.2 ppm
butyl benzyl phthalate	n.c.

[1]Footnote 2, Table 4-1.

[2]EPA has recommended human health effects criteria of zero (0) for carcinogens, but notes that this level may currently be infeasible. The Agency provides criteria for achieving various levels of protection on an interim basis. The levels which may result in a 10^{-5} incremental increase of cancer risk over a lifetime are presented in parentheses in ppb unless noted. These figures would permit one case of cancer per 100,000 people exposed.

[3]Criterion for "halomethanes".

[4]n.c. -- denoted no criteria set for human health due to insufficient data.

nor environmental consequences. As these contaminants exit from the shallow ground-water system, they encounter potential receptors. Tinker AFB is within the recharge area of the regional aquifer system (the Garber-Wellington). Where contaminants are recharged to that regional system, they have direct human health implications. Where waters come to the land surface, either as seeps or as ground-water outflow to streams, there exists the potential for human contact and exposure. Within the context of the IRP program, the installation boundary is considered to be a de-facto receptor with human health implications. If alternative (higher) limits were to be established specifically for Tinker AFB, a formal risk assessment would be required. Since the formal assessment of environmental and human health risks associated with the occurrence of contaminants is beyond the scope of this program, the use of human health standards and criteria is both reasonable and prudent.

4.2 Results of Phase II (Stage 1) Investigation

This section presents the results of geologic, hydrologic, and analytical data obtained during the Phase II (Stage 1) investigation. The discussions are organized by zone, with appropriate references to base-wide trends or features common to more than one zone. Zones of Investigation are shown on Figure 4-1. Results from the work performed at each zone are presented in terms of the topography, geology and hydrology, and ground-water chemistry observed during the investigation.

4.2.1 Zone 1 (Landfills 1 through 4)

Work performed at Zone 1 consisted of the installation of three ground-water monitor wells, completion of one exploratory boring to a depth of 150 feet, and the sampling and analysis of water from the monitor wells installed by Radian, as well as the eight existing wells along Crutcho Creek, pond, and the one existing leachate seep. The results of the hydrogeologic and chemical data are discussed in the following paragraphs.

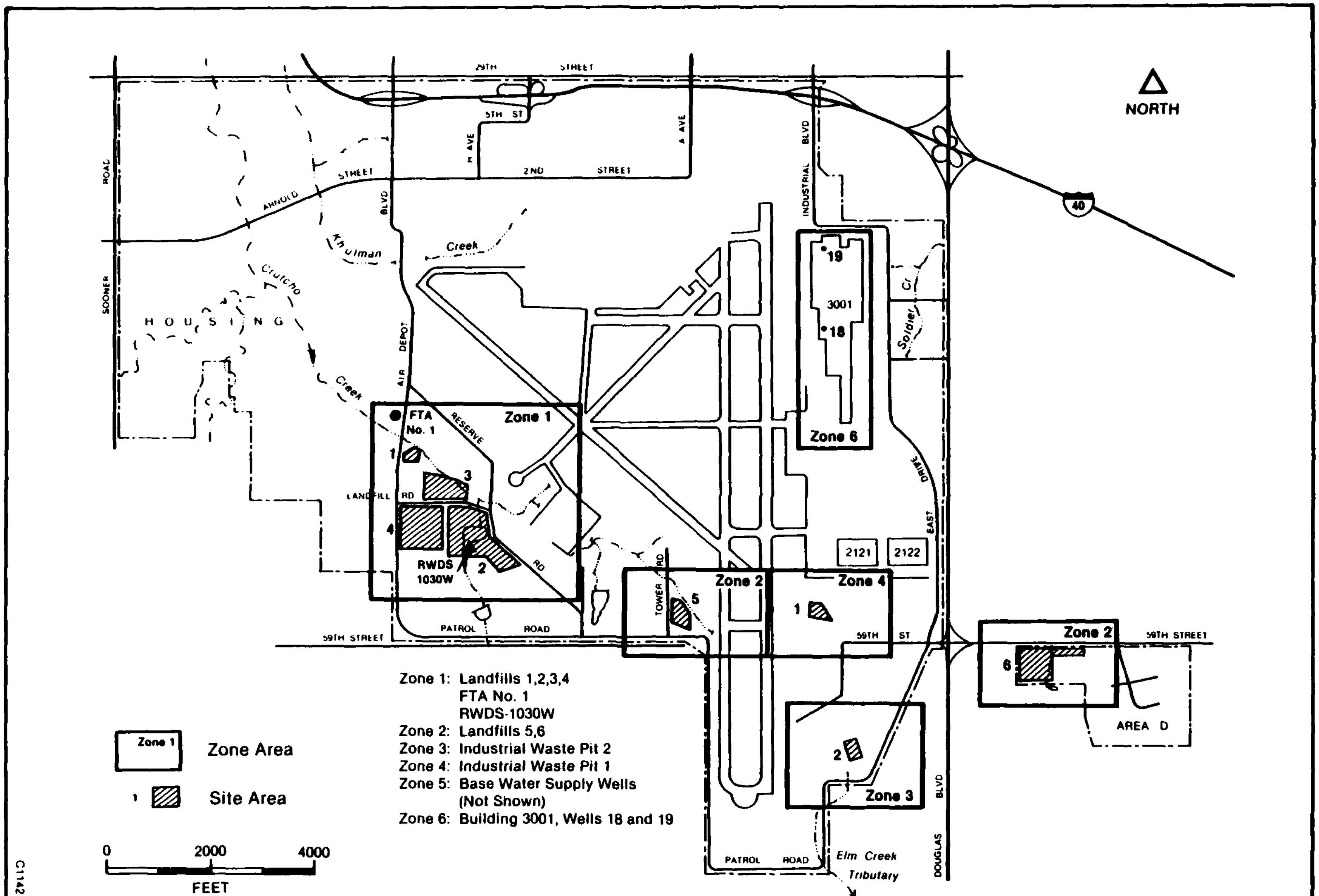

Figure 4-1. Zones of Investigation, Tinker AFB.

Topography

Zone 1 is located on land that slopes to the northeast toward Crutcho Creek, which forms the northern boundary of the zone and the major surface water drainage. Relief is approximately 35 feet, ranging from 1250 feet at the south side of Landfill 4 to about 1215 feet at Crutcho Creek just northwest of Patrol Road. The landfills occupy most of the area of the zone and form distinct topographic features expressed as hummocky, weed-covered land normally several feet higher than the surrounding undisturbed land. Portions of Landfill 2 are submerged under a pond, whose shoreline reflects the relict trenches of the landfill.

Figure 4-2 illustrates the disposal areas in Zone 1, as well as the locations of the monitor wells, exploratory boring, and sampling points for the investigation. Existing monitor wells 6 through 8, which were sampled as part of the Zone 1 effort, are discussed in Section 4.2.2 (Zone 2), below.

Geologic Features

Geologic features of Zone 1, as observed during the installation of three monitoring wells and the exploratory boring, are consistent with the regional geologic setting of the Oklahoma City area and the known geologic conditions at Tinker AFB. Generally, the substrate consists of a dark brown, moist clayey soil with organic matter, underlain by 20 to 30 feet of red shale (Fairmont Shale) with thin lenses and layers of sandstone, in turn underlain by a minimum of 120 feet of water-bearing sandstone (Garber Sandstone) with shaley zones. This geologic picture is based on logs of three borings for monitoring wells installed to a maximum depth of 80 feet, and one exploratory boring drilled to a depth of 150 feet (Appendix D). Figure 2-5 provides a generalized east-west cross-section illustrating the major geologic units.

The Fairmont Shale (Hennessey Group) strata, consisting of predominantly shale, are difficult to distinguish from the upper portion of the underlying Garber Sandstone, which is reported to be shaly. The contact

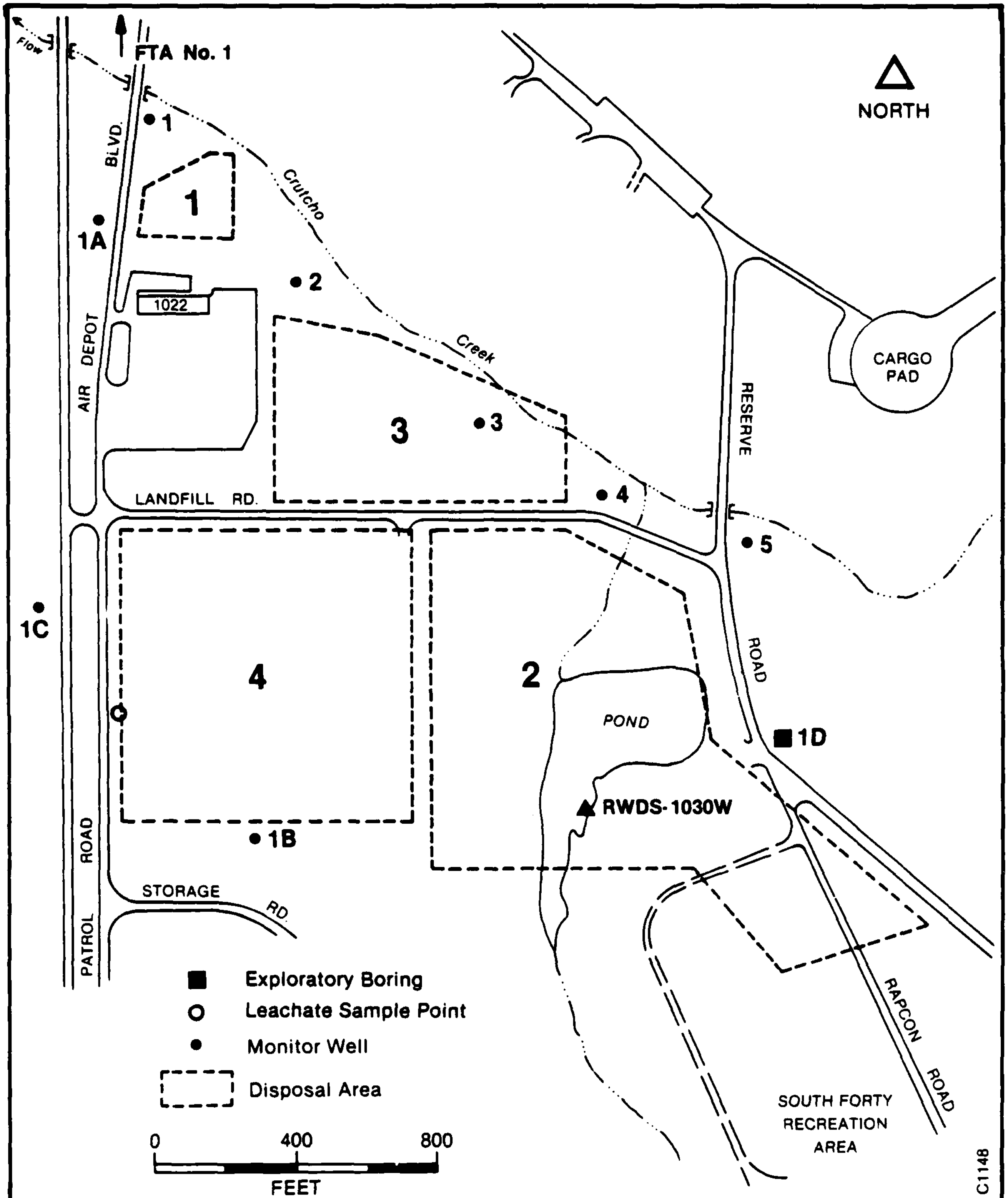

Figure 4-2. Location of Sample Points, Zone 1.

between the Fairmont Shale and Garber Sandstone is gradational throughout the Oklahoma City area. Published geologic maps differ in the interpretation of the surface geology at Tinker AFB; Wood and Burton (1968) extend the Fairmont Shale (Hennessey Group) over most of the base, but Bingham and Moore (1975) map the Garber Sandstone over most of the base and show the contact with the Fairmont Shale to lie, for the most part, south of S.E. 59th Street. The lithology of cuttings obtained during Phase II (Stage 1) borings supports the Wood and Burton (1968) version that shows the Fairmont SHale convering most of Tinker AFB.

Near Crutcho Creek, the soil zone is thicker and is underlain by a correspondingly thicker sequence of weathered red shale with occasional lenses and layers of poorly-consolidated sandstone. Logs of borings performed at monitoring well 1A and the five existing monitoring wells along Crutcho Creek demonstrate this sequence (Appendix D; Finn, 1981).

Occurrence of Ground Water

Ground water occurs at depths ranging from 4 feet to 50 feet below the land surface, and reflects, in general, the topography of the land surface. Water levels are highest near Crutcho Creek, where the shallow ground water in predominantly weathered materials appears to be closely related to the creek stage. Away from the creek and south toward higher elevations, the ground water is deeper and occurs at or several feet below the contact between the Fairmont Shale and the Garber Sandstone. The ground water is unconfined, with the water table related primarily to the occurrence of permeable strata (i.e., the Garber Sandstone). The Fairmont strata are mostly dry, with only minor and limited zones of perched water (e.g., log of boring 1D, Appendix D).

Wells completed in the upper 10 feet of the saturated zones generally yielded less than 1 gpm. The low yield is related both to the relatively thin zone of strata contributing water to the well and the silty character of the sandstone. It was observed at boring 1D that continued drilling into the Garber Sandstone resulted in increasing flow of water at greater depths. The silt content of the sandstone decreased significantly below a depth of 90 feet below the surface.

Perched ground water also exists within Landfill 4 (and possibly other landfills), emerging as both discrete seeps and broad zones of seepage along the margins of the landfill. The volume of seepage at the land surface is correlatable with rainfall events; for example, active seeps were observed at the west side of Landfill 4 within several weeks of heavy rainfall that occurred in October 1983, but these seeps were nearly dry in February 1984 following a relatively dry spell. Landfill leachate that emerges at the surface collects in roadside ditches and flows to the north to Crutcho Creek.

Ground-water flow, as inferred from water-level elevations in wells away from the influence of Crutcho Creek, is generally to the west. The results of water level interpretations for Zone 1 are consistent with the results obtained in other zones, indicating a hydrogeologic picture consistent with the regional flow patterns observed in the Oklahoma City area.

Ground-Water Quality

After installation, each of the Phase II (Stage 1) monitor wells was sampled for chemical analysis. The eight existing monitor wells (numbered one through eight) were also sampled at this time. The results of analyses are given on Table 4-3. Samples from monitor wells 1A, 1B, and 1C were analyzed for acid/neutral extractable organic priority pollutants (modified EPA Method 625). Samples from monitor wells 2 and 4 were resubmitted for modified Method 625 analysis, based on the results of total organic carbon analyses performed in the specific parameter schedule. No additional compounds were detected by modified Method 625. Complete reports of all analyses are provided in Appendix H. These data are discussed in Section 4.3.

Other Samples

In addition to the monitor well samples, selected surface water samples were also collected. The recreation pond overlying Landfill 2 was sampled by compositing grabs from randomly selected points. The leachate seep on the west fence of Landfill 4 was sampled, but leachate seeps at other landfills remained dry throughout the period. Results of analyses are also shown on Table 4-3. These data are also discussed in Section 4.3.

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TABLE 4-3. RESULTS OF CHEMICAL ANALYSES, ZONE 1, TINKER AFB

Parameter (mg/L)	Monitor Well											Leachate	Pond
	1A	1B	1C	1	2	3	4	5	6	7	8		
Cadmium	0.008	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Cyanide	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.02	<.01	<.01
Chromium	0.008	0.007	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	0.005	0.023	<.001
Copper	0.009	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Iron	0.025	<.008	0.017	<.008	<.008	<.008	<.008	<.008	<.008	<.008	0.021	5.0	0.25
Mercury	0.0005	0.0006	0.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0002	<.0005	<.0005
Manganese	0.23	0.013	0.007	0.76	0.71	1.2	1.1	0.053	0.26	2.3	0.110	0.33	0.010
Nickel	0.008	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	<.003	0.73	<.003
Oil & Grease	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Lead	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002
Phenol	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	<.005	0.21	<.005
Total Organic Carbon	5	<1	<1	9	37	17	33	5	14	7	2	340	5
Total Organic Halogen	0.08	0.06	0.06	0.05	0.04	<.01	0.20	<.01	<.01	<.01	0.03	1.5	<.01
Zinc	<.003	<.003	<.003	<.003	<.003	<.003	0.044	<.003	<.003	<.003	0.015	<.003	<.003
Herbicides													
2,4-D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,4,5-TP (Silvex)	<5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pesticides (EPA Method 608)	ND[1]	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Acid/Neutral Extractable Organic Priority Pollutants (Modified EPA Method 625)	ND	ND	ND	-[2]	ND	-	ND	-	-	-	-	-	-

[1]ND = Not Detected.
[2]- = Not Analyzed.

4.2.2 Zone 2 (Landfills 5 and 6)

Work performed at Zone 2 consisted of the installation of two groundwater monitor wells (one at Landfill 6 and one at Landfill 5) and the sampling and analysis of water from the monitor wells. The results and significance of the hydrogeologic and chemical data are discussed in the following paragaphs.

Topography

Zone 2 is separated into two distinct areas with over 1 mile of separation (Figure 4-1). It exhibits the same types of topograhic features that occur in other zones. Landfill 5 (Figure 4-3), located just southwest of Crutcho Creek and upstream of Zone 1, is built up on the order of 5 to 10 feet above the surrounding land, which slopes gently to the northeast toward Crutcho Creek. Similarly, Landfill 6 (Figure 4-4) is higher than the surrounding land as it is located on the crest of a low hill just south of S.E. 59th Street and east of Douglas Boulevard. Both landfills are relatively recent features, having been active within the last 5 to 15 years. Accordingly, there is patchy vegetation on both fill surfaces. There is also recent disruption of the surface of Landfill 5 due to nearby construction.

Geologic Features

Results of monitor well installation show that the geologic setting at sites in Zone 2 is essentially the same as the geologic setting at Zone 1. A near-surface zone of soil and weathered shale, normally 3 to 5 feet thick, is underlain by dry, red Fairmont Shale. The shale is in turn underlain by fine-grained sandstone of the Garber Sandstone. Logs of borings (Appendix D) for wells 2A (at Landfill 6) and 2B (at Landfill 5) include detailed descriptions of the geologic section. Figure 2-5, a geologic cross-section of the southern part of the base, illustrates the continuity of geologic strata from zone to zone. The dip of the strata is to the west at a shallow angle, which is consistent with the regional geologic framework of Permian-age strata in central Oklahoma.

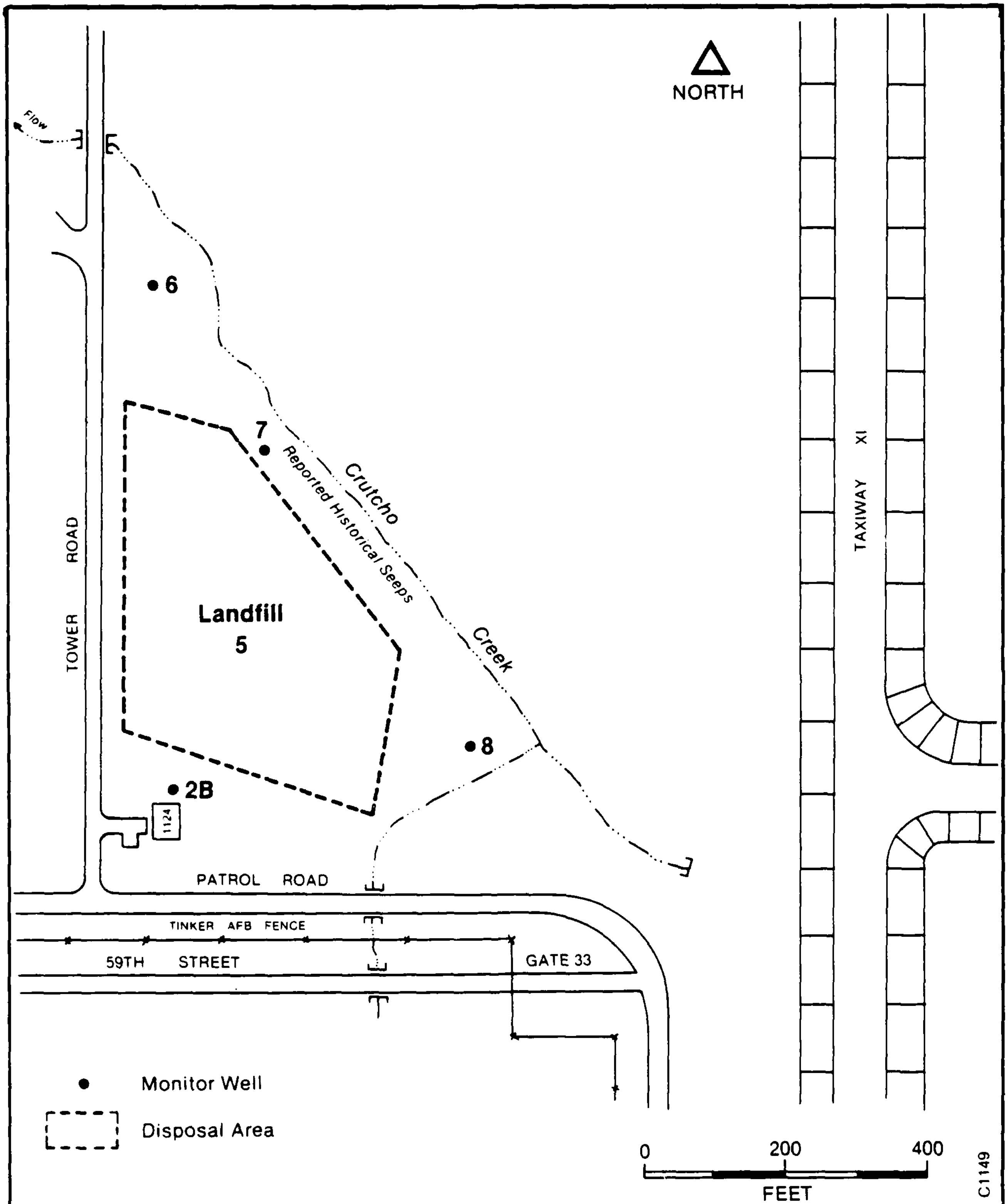

Figure 4-3. Location of Sampling Points, Zone 2 (Landfill 5), Tinker AFB.

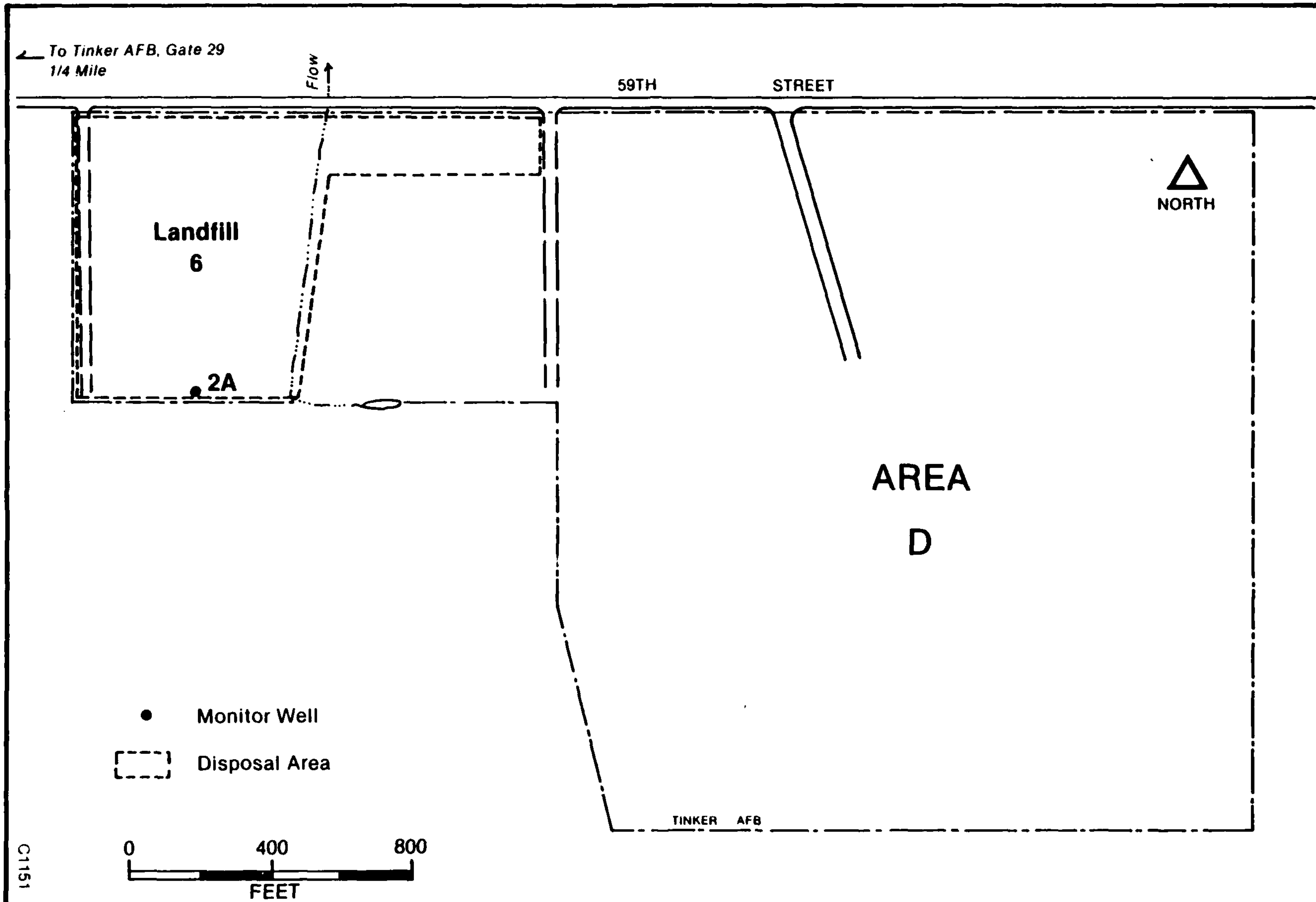

Figure 4-4. Location of Sampling Points, Zone 2 (Landfill 6), Tinker AFB.

Occurrence of Ground Water

The occurrence of ground water in Zone 2 is similar to the occurrence of ground water in other zones. In general, the position of the water table is 10 to 20 feet below the contact between the Fairmont Shale and the Garber Sandstone. Local intervals of perched water may be present within limited zones of sandstone within the shale, although perched water was not observed during the air-rotary drilling operations at either landfill.

Ground-water levels near Crutcho Creek, measured in the pre-Phase II (Stage 1) monitor wells 6, 7, and 8, are somewhat higher than the water level in monitor well 2B and reflect the hydraulic communication between water in the creek and near-surface deposits in the vicinity of the creek. The position of the water table observed in monitor wells 2A and 2B is consistent with the regional water-level pattern as illustrated on the geologic cross-section (Figure 2-5). Ground-water flow, inferred from the areal distribution of hydraulic heads in the Garber Sandstone, is to the south. With only one data point, insufficient control exists to determine flow patterns (direction) in the vicinity of the landfills.

Ground-Water Quality

After installation, each of the monitor wells was sampled for chemical analysis. The results of the analyses are shown on Table 4-4. Samples were analyzed for acid/neutral extractable organic priority pollutants (modified EPA Method 625); only compounds detected are shown. Complete reports of all analyses are provided in Appendix H. These data are discussed in Section 4.3.

4.2.3 Zone 3 (Industrial Waste Pit No. 2)

Work performed at Zone 3 consisted of a geophysical (electromagnetic, EM) survey, shallow soil coring at six locations, installation of 2 shallow ground-water monitor wells within the boundary of the disposal area, installation of 1 deep ground-water monitor well away from the disposal area,

TABLE 4-4. RESULT OF CHEMICAL ANALYSES, ZONE 2, TINKER AFB

Parameter mg/l (except as noted)	Well 2A	Well 2B
Barium	0.21	0.45
Cadmium	0.006	<.002
Cyanide	<.01	<.01
Chromium	<.001	<.001
Copper	<.001	<.001
Iron	0.23	<.008
Mercury	0.0004	<.0005
Nickel	<.003	<.003
Oil & Grease	<0.10	<0.10
Lead	<.002	<.002
Phenol	<.005	<.005
Total Organic Carbon	<1	9
Total Organic Halogen	<.01	<.01
Zinc	0.34	<.003
Herbicides		
2,4-D	ND	ND
2,4,5-TP (silvex)	ND	ND
Pesticides (EPA Method 608)	ND	ND
Acid/Neutral Extractable Organic Priority Pollutants (Modified EPA Method 625)		
butyl benzyl phthalate	ND	2.3 μg/L

and sampling and analyses of soil and ground water. The results of the hydrogeologic, geophysical, and chemical data are discussed in the following paragraphs.

Topography

Zone 3 is located on the southeast corner of Tinker AFB (Figure 4-1) on land ranging in elevation from approximately 1280 feet (near Patrol Road) to over 1310 feet, the highest elevation at Tinker. The disposal area was sited at the crest of a low hill, with drainage away from the site in all directions. The area is now covered with grass and shows no sign of previous surface disturbance.

Figure 4-5 illustrates the suspected disposal area, as well as the locations of the cores, monitoring wells, and the limits of the geophysical survey.

Geologic Features

Geologic data developed for Zone 3 resulted from three primary activities: geophysical (EM) surveying, geologic sampling during coring and drilling operations, and observations of water levels during and after coring and monitor well installation.

The geologic picture at Zone 3 is virtually the same as at other zones. The major geologic units are a thin soil cover, underlain by dry red Fairmont Shale, in turn underlain by sandstone of the Garber Sandstone. Logs of boring and drilling operations (Appendix D) provide additional details of the geologic section. The major geologic features of interest in the investigation of Zone 3 are the near-surface phenomena (conductivity anomalies and disturbed earth materials) associated with the former Industrial Waste Pit No. 2. The purpose of the geophysical survey and shallow coring efforts was to investigate in detail the near-surface geologic conditions in view of the potential for ground-water contamination.

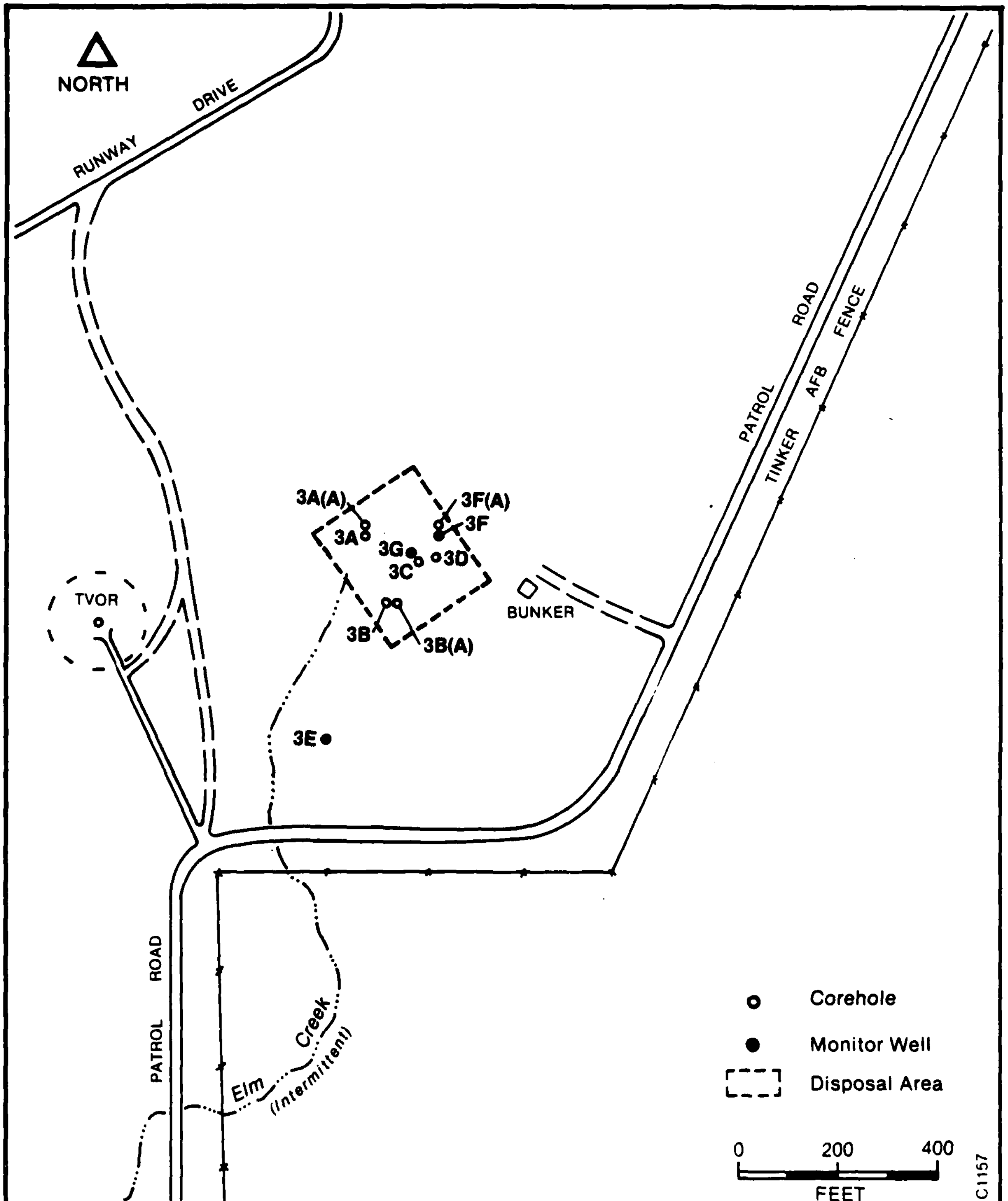

Figure 4-5. Location of Sampling Points, Zone 3, Tinker AFB.

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Geophysical Survey

Ground conductivity was read directly using the Geonics EM31 and EM34-3. By using both the EM31 and EM34-3, the apparent conductivities were measured at two different depths of investigation. The depth of investigation is approximately 12 feet with the EM31, and approximately 50 feet with the EM34-3 with 20 meters of separation (see Section 3.1.1). With measurements at two different effective depths of investigation, an estimate can be made of the thickness of the area of interest. The values measured at each station are shown on Figures 4-6 and 4-7 for the EM31 and EM34-3, respectively.

Both the apparent conductivity contour maps show highs over the expected disposal site area. The EM31 shows background values of ground conductivity between 50 to 70 milimhos/m away from the pit, consistent with the EM31 readings, and values as high as 80 millimhos/m over the pit. The two maps of ground conductivity indicate a close correlation of results between the two instruments. The conductivity contour map of the EM31 readings shows an area of conductivity values in excess of 80 millimhos/m to the southwest of the pit area, corresponding to a shallow gully draining to Elm Creek. Airphotos taken during the operating of the waste pit suggest that an overflow feature may correspond to the present-day location of the gully; the relatively high conductivity values may be a reflection of soil contamination away from the pit itself. The cause of the isolated "high" north of the bunker is not known. Neither airphotos taken during pit operation nor current visual inspection reveal any evidence of waste disposal or other disturbance. The magnitude of the anomaly is small (65 millimhos) in comparison with local background, which is in the mid 50's.

Both over the pit and over the "overflow gully" to the southwest, the conductivity values measured with the EM31 are higher than those measured with the EM34-3. This indicates that conductivity values, and probably any soil contamination, decrease with depth. Prior to field coring operations at the location of the pit, it was concluded that the thickness of any contaminated soil in the center of the pit would be on the order of 15 ($\pm$3) feet

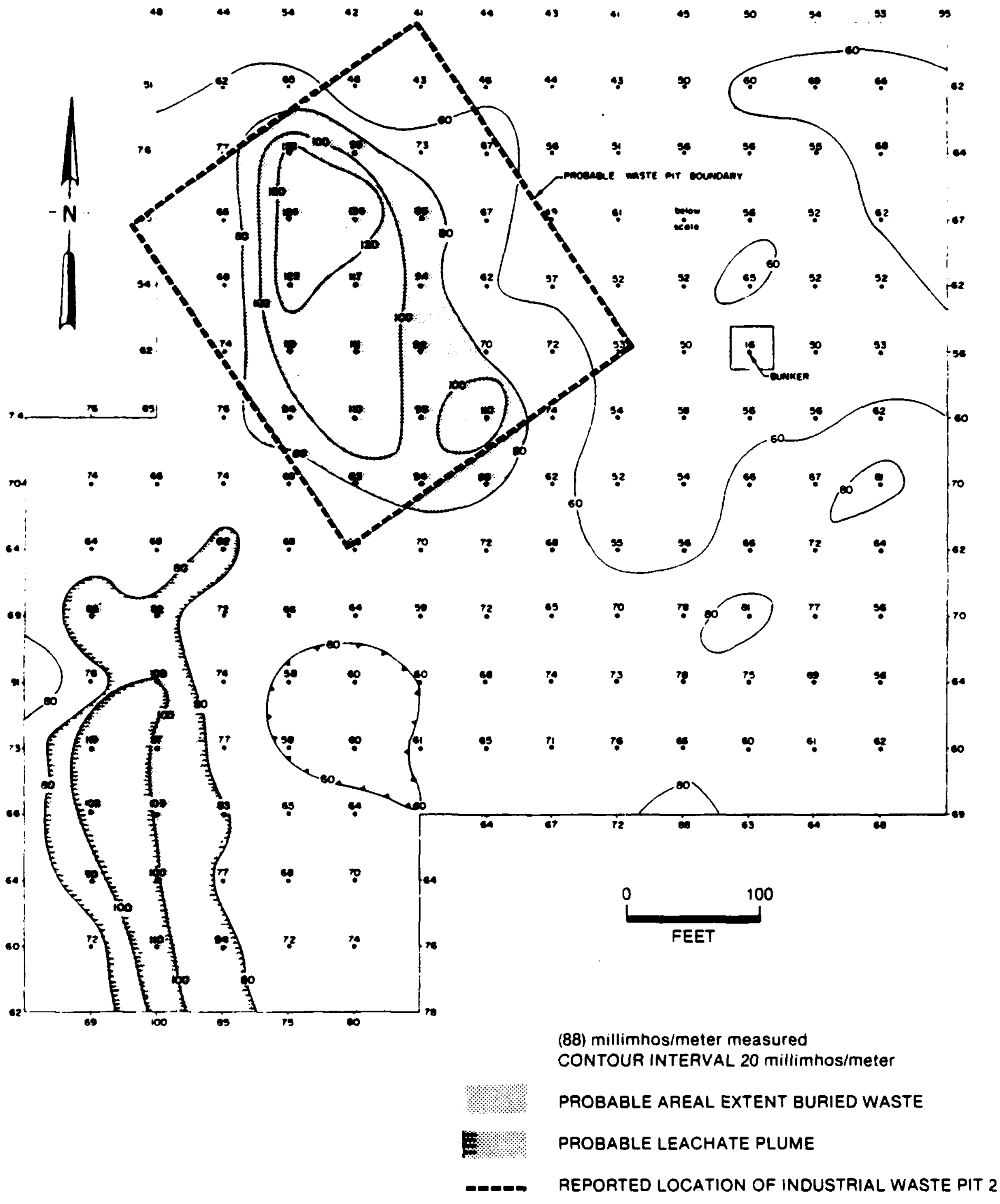

Figure 4-6. Geophysical Survey Results, EM31, Zone 3, Tinker AFB.

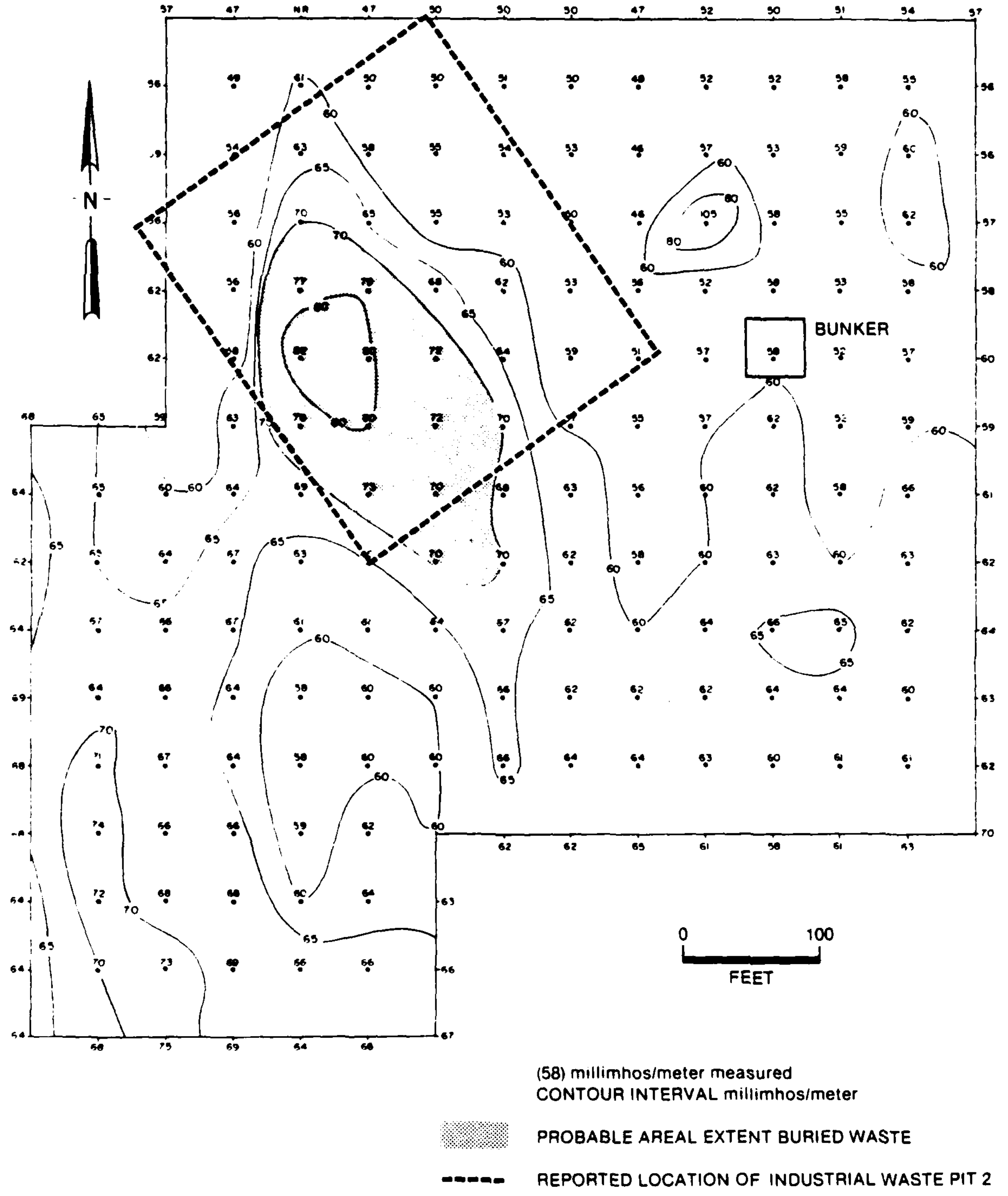

Figure 4-7. Geophysical Survey Results, EM34-3, Zone 3, Tinker AFB.

below the land surface. Results of coring operations, discussed below, revealed that the interval of affected soil is closer to the surface (i.e., the zone associated with the waste material was thinner than expected).

Soil Sampling

Shallow soil sampling operations (described in Section 3.1.2) were conducted at the conclusion of the field geophysical survey. Results of the geophysical survey were used as an aid in selecting the locations of the cores so as to investigate the area of the waste pit. Sampling was performed at five locations in order to directly observe soil conditions at the waste pit and to provide for the installation of two shallow ground-water monitor wells.

The geologic materials varied considerably within the area of investigation. For the most part, the subsurface consisted of soil and fill, underlain by weathered and unweathered shale. Augering and sampling were quite difficult in unweathered shale, with refusal typically at or slightly below the weathered shale - unweathered shale contact. Split-spoon samples from directly over the conductivity anomalies generally yielded near-surface samples of soil with a contaminated appearance: dark brown, moist, clayey fill-like material. The logs of borings for Zone 3 (Appendix D) provide additional and specific details. It is believed that the fill-like material simply represents soil that was pushed or placed into or over the waste pit during reclamation in the mid-1960s.

Rotary Drilling

Sampling of deeper stratigraphic horizons (at monitor wells 3E) southwest of the waste pit revealed a sequence essentially identical to the geologic setting at Zones 1 and 2. No evidence of soil or ground-water contamination was observed during the drilling of 3E.

Occurrence of Ground Water

Ground water at Zone 3 was found to occur under three different conditions: in a shallow, saturated interval extending from just below the land surface to the top of the unweathered shale; in a sandstone body isolated in a dominately shale section directly below the waste site; and in the regional water-table aquifer continuous within the base.

The shallow saturated interval at the waste site corresponds roughly to the soil zone and contains water that exists sporadically across the zone. Water was observed near the surface in some boreholes, but not at all in others. Directly below the waste, perched water was observed in the sandstone body (approximately 16 to 20 feet below land surface) monitored by well 3F. After completion of the coring operations to a depth of 30 feet, the hole was observed to be dry; after a period of time water collected in the borehole to a level of 16 feet below the land surface. The water was bailed out of the borehole in order to test the response of the water level. The water level had fully recovered within one day. At boring 3C, wet cuttings were noted at 5 feet below land surface. Upon completion of the boring in clay/shale at 11 feet, the water level stabilized at 1.2 feet below land surface. The position of the water table observed at 3C was not affected by the bailing at 3F.

The saturated interval in the soil probably represents the accumulation of infiltrated rain water that collected in surface depressions; there appears to be no evidence for significant lateral or downward migration of this water. This conclusion is based on the significantly different water levels in boreholes 3C (soil water) and 3F (water from sandstone body). Most boreholes in which water was observed required hours or days to produce the water, demonstrating the very low permeability of the clayey soil. Monitor well 3G was later installed to a depth of 8 feet and adjacent to borehole 3C (which had been grouted) in order to allow for the collection of samples of ground water over time.

Southwest of the waste disposal area, monitor well 3E was completed to a depth of 80 feet below the land surface. Ground water was observed during drilling at a level 63 feet below the surface, approximately 30 feet below the Fairmont Shale-Garber Sandstone contact. This ground water represents the regional water table observed in the other Phase II (Stage 1) monitor wells installed in other zones.

Soil Chemistry and Ground-Water Quality

Split-spoon samples collected in the coring operations were retained and examined for evidence of contamination. Based on the apparent geometry of the pit, ten samples of soil were selected for detailed analysis, consisting of selected metals, total organic carbon, total organic halogen, and phenols. The samples selected for analysis were chosen such that the vertical and horizontal distribution of chemical species in geologic materials within and below the pit could be evaluated, as shown on Table 4-5. Based on the results of these analyses, one sample (the sample with the highest level of total organic carbon) was resubmitted for modified EPA Method 625 analysis. Results of these analyses are provided on Tables 4-6 and 4-7.

After installation, each of the monitor wells was sampled for chemical analysis. The results of analyses are shown on Table 4-8. Samples were analyzed for acid/neutral extractable organic priority pollutants (modified EPA Method 625); only compounds detected are shown. Complete reports of all analyses are provided in Appendix H. These data are discussed in Section 4.3.

4.2.4 Zone 4 (Industrial Waste Pit No. 1)

Work performed at Zone 4 consisted of geophsical (EM) survey, shallow soil coring at six locations, installation of two shallow ground-water monitor wells within the boundary of the disposal area, installation of 1 deep ground-water monitor well away from the disposal area, and sampling and analyses of soil and ground water. Figure 4-8 illustrates the suspected disposal area, as well as the locations of the cores, monitor wells, and the limits of the geophysical survey. The results of the hydrogeologic, geophysical, and chemical data are discussed in the following paragraphs.

TABLE 4-5. ZONE 3 SOIL SAMPLES FIELD-SELECTED FOR CHEMICAL ANALYSIS

Sample	Depth	Description	Reason for Selection
3Aa	3.5-4.5	brown-red clay	Base of fill
3Aa (alt)	2.5-3.8	gray-red fill	Waste/soil adjacent to original hole 3A
3Ab	8.5-10.0	red clay	Moderate depth below fill
3Bb	8.0-9.5	red clay	Moderate depth below fill
3Bd	14.1-18.0	red shale	Deep sample below fill
3Be	20.5-21.5	red shale	Deep sample below fill
3Ca	3.0-4.4	waste-fill	Waste(?)
3Cb	8.0-9.4	clay-shale	Moderate depth below fill
3Fb (alt)	4.5-4.8	hard red clay	Bottom of fill/waste
3Fe (alt)	5.4-5.8	hard red clay	Immediately below fill/waste

TABLE 4-6. RESULTS OF SOILS ANALYSES, ZONE 3, TINKER AFB

Parameter (µg/g, except as noted)	Soil Sample									
	3Aa	3Aa (alt)	3Ab	3Bb	3Bd	3Be	3Ca	3Cb	3Fb	3Fc
Cadmium	3.2	2.0	0.49	0.25	0.20	<.15	23	1.2	0.25	<.020
Cyanide	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Chromium	8.9	6.2	4.5	3.8	2.9	4.0	750	5.7	15	4.0
Copper	7.1	4.1	11	5.6	5.6	5.7	130	13	5.1	2.3
Mercury	4.0	4.5	4.1	3.5	3.4	4.0	3.5	3.5	3.8	3.8
Nickel	38	13	13	7.2	5.4	6.0	40	11	7.9	5.7
Oil & Grease (mg/g)	2	5	2	0.5	1.5	0.5	6	1	1.5	1
Lead	5.2	2.5	2.9	2.5	1.8	1.9	41	3.3	9.2	1.6
Phenol	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
Total Organic Carbon (%)	0.11	0.32	0.02	0.02	0.02	0.04	0.52	0.03	0.19	0.02
Total Organic Halogen	<1	12	<1	<1	<1	<1	14	<1	<1	<1
Zinc	9.2	3.0	12	5.9	5.0	8.2	36	7.6	16	5.7

TABLE 4-7. RESULTS OF MODIFIED EPA METHOD 625 ANALYSIS, SOIL SAMPLES 3 Ca, ZONE 3, TINKER AIR FORCE BASE

Compound	Concentration ($\mu g/g$)
1,2-dichlorobenzene	44
1,3-dichlorobenzene	1.5
1,4-dichlorobenzene	6.6
di-n-butyl phthalate	3.0

TABLE 4-8. RESULTS OF GROUND-WATER SAMPLE ANALYSES, ZONE 3, TINKER AFB

Parameter (mg/L, except as noted)	Well 3E	Well 3F	Well 3G
Cadmium	<.002	<.002	2.2
Cyanide	<.01	<.01	<.01
Chromium	<.001	<.001	12
Copper	<.001	<.001	0.15
Mercury	0.0004	0.0006	<.0005
Nickel	<.003	<.003	82
Oil & Grease	<0.10	<0.10	70
Lead	<.002	<.002	3.3
Phenol	<.005	<.005	80[1]
Total Organic Carbon	<1	3	4000
Total Organic Halogen	<.01	<.01	3.4
Zinc	0.016	0.024	29
Acid/Neutral Extractable Organic Priority Pollutants (modified EPA Method 625)			
1,2-dichlorobenzene	ND	ND	20
phenol	ND	ND	220

[1]Probable low bias due to interferences with colorimetric procedure, large dilution required for analysis.

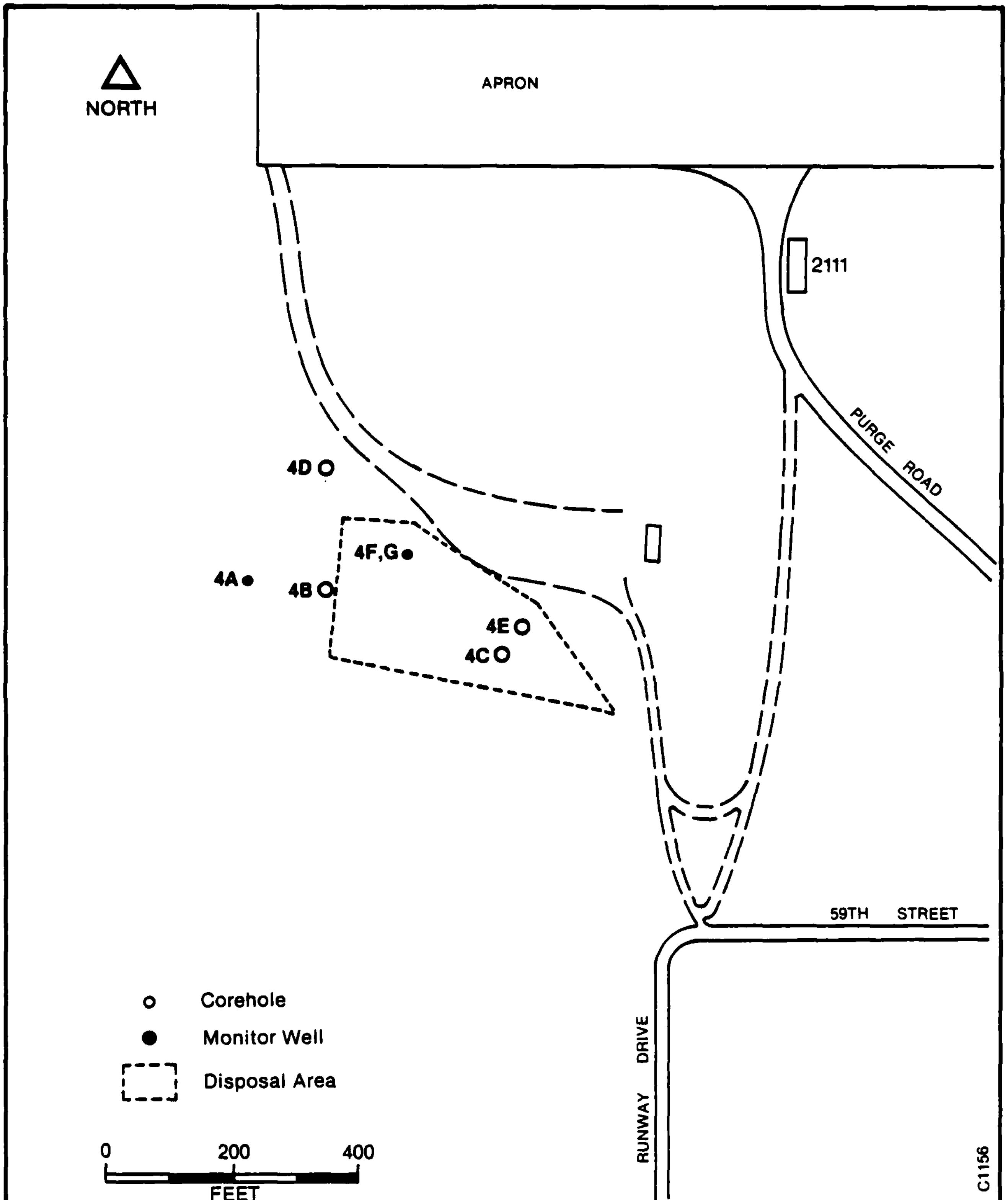

Figure 4-8. Location of Sampling Points, Zone 4, Tinker AFB.

Geologic Features

Geologic data developed for Zone 4 resulted from three primary activities: geophysical (EM) surveying, geologic sampling during coring and drilling operations, and observations of water levels during and after coring and monitor well installation.

The geologic picture at Zone 4 is virtually the same as at other zones. The major geologic units are a thin soil cover, underlain by dry, red Fairmont Shale, in turn underlain by sandstone of the Garber Sandstone. Logs of boring and drilling operations (Appendix D) provide additional details of the geologic section. The major geologic feature of interest in the investigation of Zone 4 are the near-surface phenomena (conductivity anomalies and disturbed earth materials) associated with the former Industrial Waste Pit No. 1. The purpose of the geophysical survey and shallow coring efforts was to investigate in detail the near-surface geologic conditions in view of the potential for ground-water contamination.

Geophysical Survey

Ground conductivity was read directly using the Geonics EM31 and EM34-3. By using both the EM31 and EM34-3 (10m and 20m of separation) the apparent conductivities were measured at different depths of investigation. The values measured at each station are shown on Figures 4-9, 4-10, and 4-11 for the EM31 and EM34-3 (10m and 20m) respectively.

Background conductivity values of less than 65 millimhos/m were observed with all three methods of investigation. These values are consistent with the background values obtained at Zone 3. A major conductivity anomaly was observed in the southeast corner of the grid on both the EM31 and EM34-3 (20m) contour maps; the anomaly was not observed on the EM34 (10m) grid. This linear anomaly was not observed with the EM34 (10m) due to the 50 foot spacing between readings resulting in either the transmitter or receiver being too far away to observe the anomaly. Most of the other areas of the suspected waste

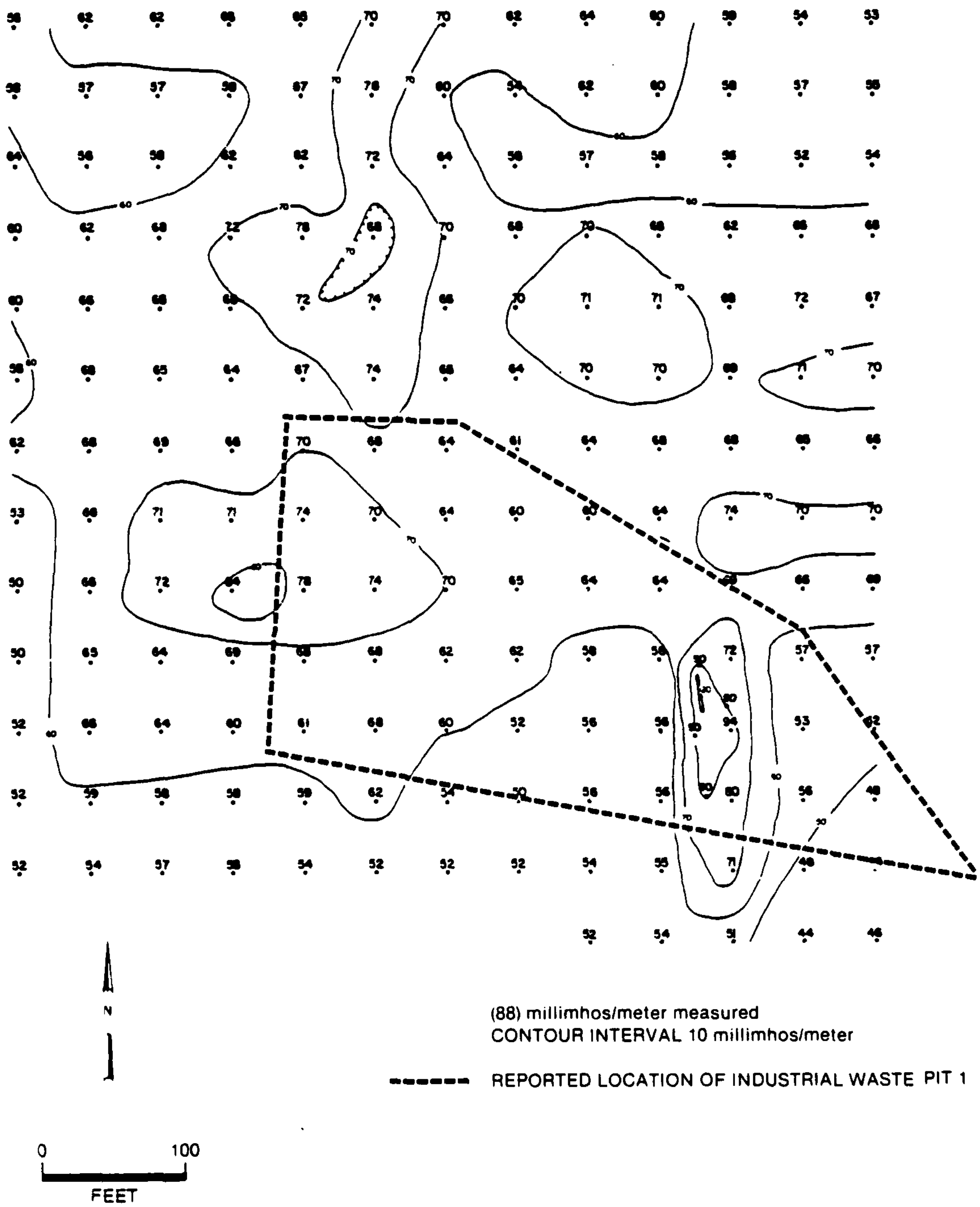

Figure 4-9. Geophysical Survey Results, EM31, Zone 4, Tinker AFB.

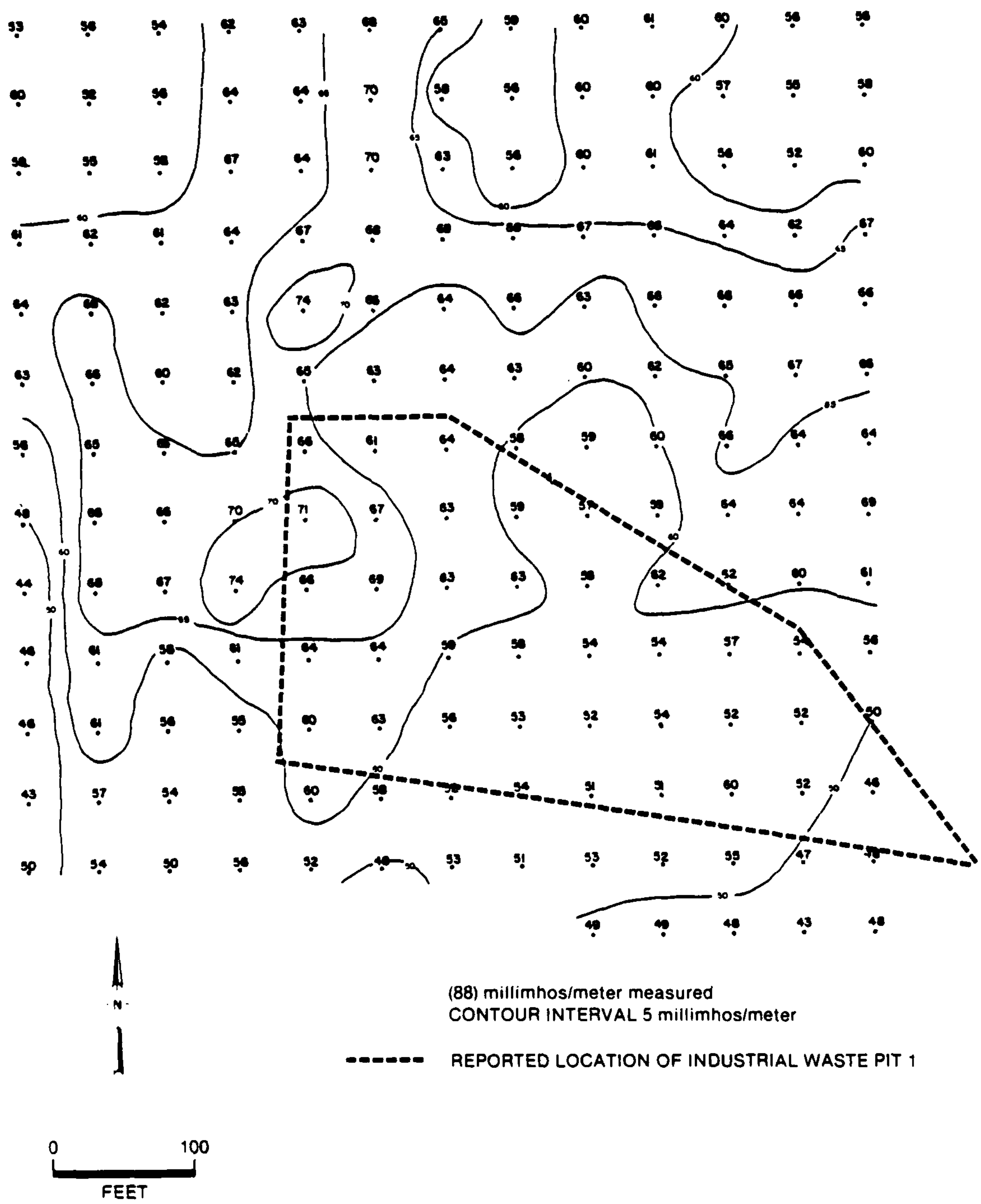

Figure 4-10. Geophysical Survey Results, EM34-3 (10m spacing), Zone 4, Tinker AFB.

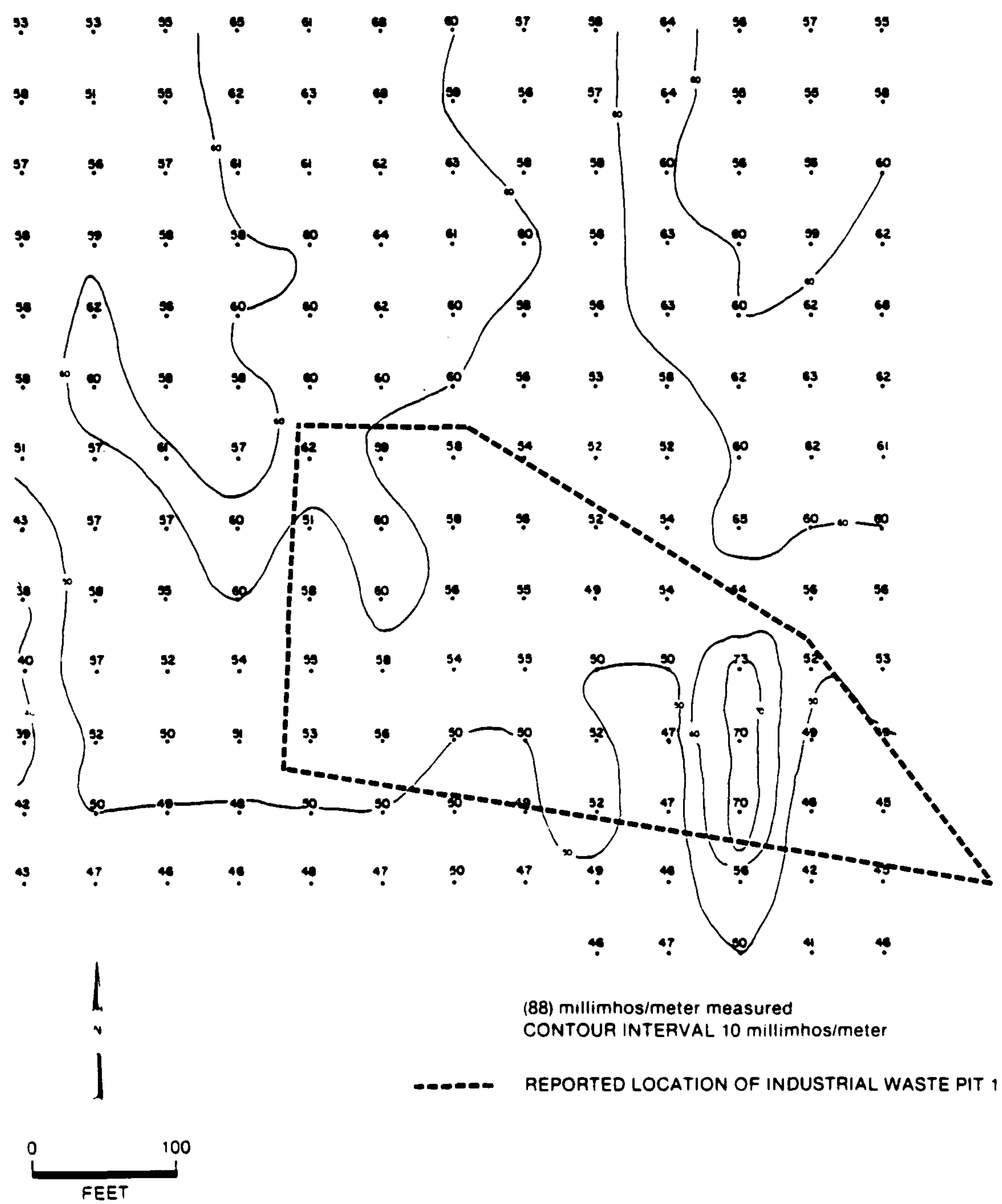

Figure 4-11. Geophysical Survey Results, EM34-3 (20m spacing), Zone 4, Tinker AFB.

disposal area were observed to have conductivity levels on the order of 5 to 10 millimhos above the background conductivity levels.

Soil Sampling

Shallow soil sampling operations (described in Section 3.1) were conducted at the conclusion of the field geophysical survey. Results of the geophysial survey were used as an aid in selecting the locations of the cores so as to investigate the area of the waste pit. Sampling was performed at six locations in order to directly observe soil conditions at the waste pit and to provide for the installation of two shallow ground-water monitor wells.

The geologic materials varied considerably within the area of investigation. For the most part, the subsurface consisted of soil and fill, underlain by weathered and unweathered shale. Augering and sampling were quite difficult in unweathered shale, with refusal typically at or slightly below the weathered shale - unweathered shale contact. Split-spoon samples from directly over the conductivity anomalies generally yielded near-surface samples of soil with a contaminated appearance: dark brown, moist, clayey fill-like material. The logs of borings for Zone 4 (Appendix D) provide additional and specific details. It is believed that the fill-like material simply represents soil that was pushed or placed into or over the waste pit during reclamation.

Rotary Drilling

Sampling of deeper stratigraphic horizons (at monitor well 4A) southwest of the waste pit revealed a sequence essentially identical to the geologic setting at Zones 1, 2, and 3. No evidence of soil or ground-water contamination was observed during the drilling of 4A.

Occurrence of Ground Water

Ground water at Zone 4 was found to occur under two different conditions: in a shallow, saturated interval extending from just below the

land surface to the top of the unweathered shale and in the regional water-table aquifer continuous within the base.

The shallow saturated interval corresponding roughly to the soil zone, contains water that exists sporadically across the zone. Water was observed in some boreholes, but not others. This saturated interval probably represents the accumulation of infiltrated rain water that collects in surface depressions; there appears to be no evidence for lateral or significant downward migration of this water. This conclusion is based on the fact that all holes completed below the soil zone were found to be dry, even where sandstone was present in the unweathered shale. Most boreholes in which water was observed required hours or days to produce the water, demonstrating the very low permeability of the clayey soil. Shallow monitor well 4G was installed to a depth of 8 feet and adjacent to monitor well 4F (which had been extended into the unweathered zone to a depth of 19.5 feet) in order to allow for the collection of samples of ground water during wet periods.

Southwest of the waste disposal area, monitor well 4A was completed to a depth of 51 feet below the land surface. Ground water was observed during drilling at a level of 39 feet below the surface, approximately 20 feet below the Fairmont Shale-Garber Sandstone contact. This ground water represents the regional water table observed in the other Phase II (Stage 1) monitor wells installed in other zones.

Soil Chemistry and Ground-Water Quality

Split-spoon samples collected in the coring operations were retained and examined for evidence of contamination. Ten samples of soil were selected for detailed analysis, consisting of selected metals, total organic carbon, total organic halogen, and phenols. The samples selected for analysis were chosen such that the vertical and horizontal distribution of chemical species in geologic materials within and below the pit could be evaluated, as shown on Table 4-9. Based on the results of these analyses, one sample (chosen to be the sample with the highest level of total organic carbon) was resubmitted for modified EPA Method 625 analysis. Results of these analyses are provided on Table 4-10.

TABLE 4-9. ZONE 4 SOIL SAMPLES FIELD-SELECTED FOR CHEMICAL ANALYSIS

Sample	Depth	Description	Reason for Selection
4B.5	1.5-3	brown clay	Probable waste/fill
4B.6	3-4.5	mottled red clay	Base of weathered zone
4C.5	8-9.5	silty brown clay	Base of weathered zone
4D.2	1.5-3	fill, charred debris	Probable waste
4E.2	1.5-3	fill	Probable waste; near EM anomaly
4E.3	3-4.5	fill	Probable waste; near EM anomaly
4E.4	8-9.5	brown-red clay	Directly below waste
4E.5	13-14.5	red shale	Bedrock below soil/waste
4F.2	1.5-3	fill, waste	4F series converted to well; waste
4F.3	3-4.5	fill, clay	Probable waste

TABLE 4-10. RESULTS OF SOILS ANALYSES, ZONE 4, TINKER AFB

Parameter (µg/g, except as noted)	Soil Sample									
	4B.5	4B.6	4C.5	4D.2	4E.2	4E.3	4E.4	4E.5	4F.2	4F.3
Cadmium	<.21	<.20	1.7	17	1.7	340	<.20	1.5	2.7	5.0
Cyanide	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chromium	4.9	8.5	11	42	9.1	78	5.6	6.3	230	32
Copper	4.2	7.1	8.5	16	15	47	3.8	9.2	24	9.7
Mercury	10	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
Nickel	3.0	11	8.3	11	14	39	5.4	9.6	22	8.0
Oil & Grease	780	410	290	206	1070	140	240	550	200	150
Lead	6.4	8.9	8.4	85	2.9	660	7.4	0.99	150	18
Phenol	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Total Organic Carbon (%)	0.12	0.10	0.08	0.15	0.10	0.13	0.10	0.12	0.08	0.05
Total Organic Halogen	0.20	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10
Zinc	5.3	9.4	7.4	57	14	1400	6.6	7.8	75	17
Acid/Neutral Extractable Organic Priority Pollutants (modified EPA Method 625)	-	-	-	-	-	None Detected	-	-	-	-

- = Not Analyzed.

After installation, each of the monitor wells was sampled for chemical analysis. The results of the analyses are shown on Table 4-11. Samples were analyzed for acid/neutral extractable organic priority pollutants (modified EPA Method 625); only compounds detected are shown. Complete reports of all analyses are provided in Appendix H. These data are discussed in Section 4.3.

4.2.5 Zone 5 (Base Water Supply Wells)

Zone 5 consists of 27 Base Water Supply wells, as shown on Figure 4-12. Each of the 20 operational wells was sampled during 7-17 Februay 1984. Samples were submitted to the laboratory for screening analyses (Total Organic Carbon and EPA Method 601). Sampling results are shown on Tables 4-12 and 4-13. Based on the results of these tests, five samples were resubmitted for analysis by EPA Methods 624 (Volatile Organic Priority Pollutants by GC-MS) and modified 625 (Acid/Neutral Organic Priority Pollutants by GC-MS). No additional compounds were discovered by these analyses. Complete reports of results are contained in Appendix H. Of the 20 wells sampled, only six displayed any trace of chlorinated organic contaminants. Observations concerning the contamination in each well are provided in Section 4.3.

4.2.6 Zone 6 (Building 3001 Wells)

The Zone 6 test plan consisted of a protracted (16-hour) test-pumping of Well 18, with samples collected periodically for analysis by EPA Method 601 for trichloroethylene (TCE) and tetrachloroethylene. Well 18 was disconnected from the distribution system and pumped to waste for a 16-hour period, beginning at 0800 hours, 5 March. Samples were collected periodically for EPA Method 601 analyses. The frequency of sampling had an increasing period, such that early samples were collected at 10-minute intervals, later sampling intervals increased to as much as three hours. The results of the analyses are contained in Table 4-14. Tetrachloroethylene remained below the detection limit of 10 ug/L throughout the testing period. A plot of the TCE data is shown on Figure 4-13. The complete results of the chemical analyses are contained in Appendix H.

TABLE 4-11. RESULTS OF CHEMICAL ANALYSES, ZONE 4, TINKER AFB

Parameter (mg/L, except as noted)	Well 4A	Well 4F	Well 4G
Cadmium	<.002	(dry)	<.002
Cyanide	<.01		<.01
Chromium	0.014		<.001
Copper	0.021		<.001
Mercury	0.0004		<.0002
Nickel	0.009		0.008
Oil & Grease	<0.10		<0.10
Lead	0.006		0.022
Phenol	<.005		<.005
Total Organic Carbon	<1		43
Total Organic Halogen	0.06		<.01
Zinc	1.2		1.4
Acid/Neutral Extractable Organic Priority Pollutants (modified EPA Method 625)			
phenol	ND		1.0 μg/L

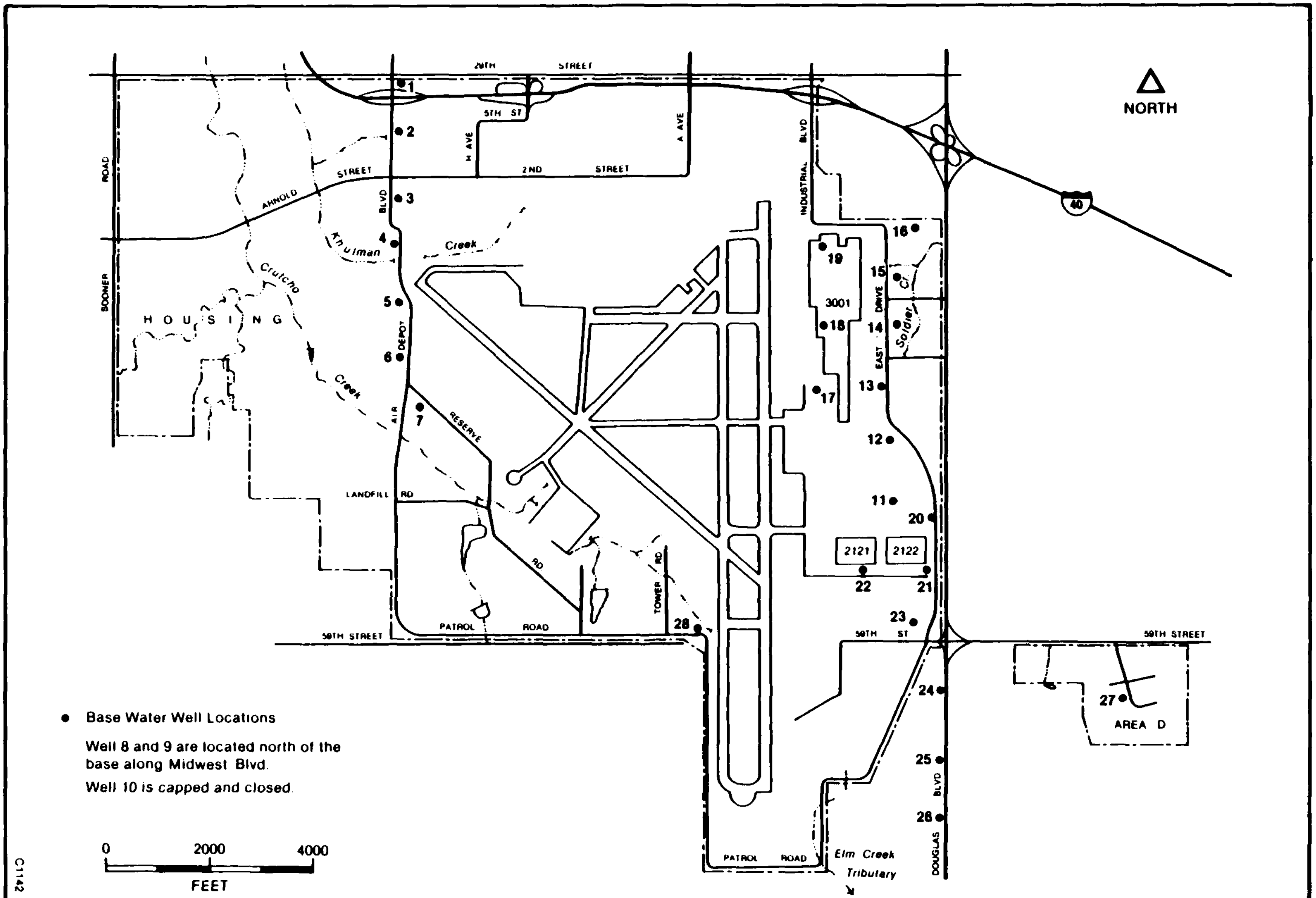

Figure 4-12. Location of Sampling Points, Zone 5 (Base Water Supply Wells).

TABLE 4-12. ZONE 5 SAMPLING DATA

Well Number	Date Sampled	Field pH	Field Cond. (umhos/cm)	Field Temp. (°F)	TOC (mg/L)	Method 601 Compounds Detected	Comments
1	2/9/84	6.8	200	54	1	None	
2	"	7.0	225	60	1	None	
3	OUT OF SERVICE						
4	2/9/84	6.5	240	58	1	None	
5	"	7.0	210	60	1	Table 4-13	
6	OUT OF SERVICE						
7	OUT OF SERVICE						
8	OUT OF SERVICE						
9	2/8/84	7.4	200	50	1	Table 4-13	Ran 5 mins. only
10	PLUGGED AND ABANDONED						
11	2/8/84	7.0	240	58	1	None	Ran 30 mins.
12	OUT OF SERVICE						
13	2/8/84	6.6	250	62	1	None	
14	"	7.0	270	60	1	Table 4-13	
15	"	6.6	270	60	1	None	Duplicate samples
16	"	6.6	290	60	1	Table 4-13	
17	OUT OF SERVICE						
18	2/9/84	6.5	430	66	1	Table 4-13	Ran 5 mins. only
18	2/17/84	6.5	550	61	3	Table 4-13	Ran 5 mins. only (resample)
19	2/17/84	6.1	260	64	1	Table 4-13	Ran 5 mins. only
19	"	6.0	300	58	1	Table 4-13	Ran 5 mins. only (resample)
20	2/8/84	6.8	260	50	1	None	Duplicate samples
21	2/7/84	7.1	260	64	1	None	
22	2/7/84	7.0	250	64	1	None	
23	"	5.5	190	60	1	None	
24	2/9/84	6.5	275	64	1	None	Air in discharge
25	2/7/84	6.9	270	60	1	None	Air in discharge Duplicate samples
26	"	5.9	250	60	1	None	
27	"	6.5	220	66	1	None	
28	OUT OF SERVICE						

TABLE 4-13. EPA METHOD 601 COMPOUNDS DETECTED IN BASE WATER SUPPLY WELLS (ZONE 5)

Compound (μg/L)	5	9	14	16	18	18 (resample)	19	19 (resample)
Methylene Chloride					1.1		0.6	
1,1-Dichloroethene					0.2			
1,1-Dichloroethane					1.4			
trans-1,2-Dichloroethene	1.7			1.2	31.7	32.8		
Chloroform		2.1						
1.2-Dichloroethane					25.8			
1,1,1-Trichloroethane					1.8			
Bromodichloromethane		0.4						
Trichloroethylene			0.7	2.2	1750	1530		
Tetrachloroethylene			0.3	0.7	30.1		7.8	2.8
Chlorobenzene					7.9			

TABLE 4-14. TRICHLOROETHYLENE CONCENTRATION DURING WELL 18 PUMP TEST

Sample Number T6-	Elapsed Time (hr:min)	Concentration (mg/L)
1	0:10	3.5
2	0:20	3.3
3	0:30	3.4
4	0:45	3.5
5	1:00	3.0
6	1:15	4.0
7	1:35	4.6
8	2:00	4.2
9	2:30	2.7
10	3:00	2.6
11	3:35	2.2
12	4:15	2.2
13	5:00	2.0
14	6:00	2.1
15	7:00	1.9
16	8:10	2.1
17	9:35	1.7
18	11:00	1.8
19	13:00	1.8
20	16:00	1.8

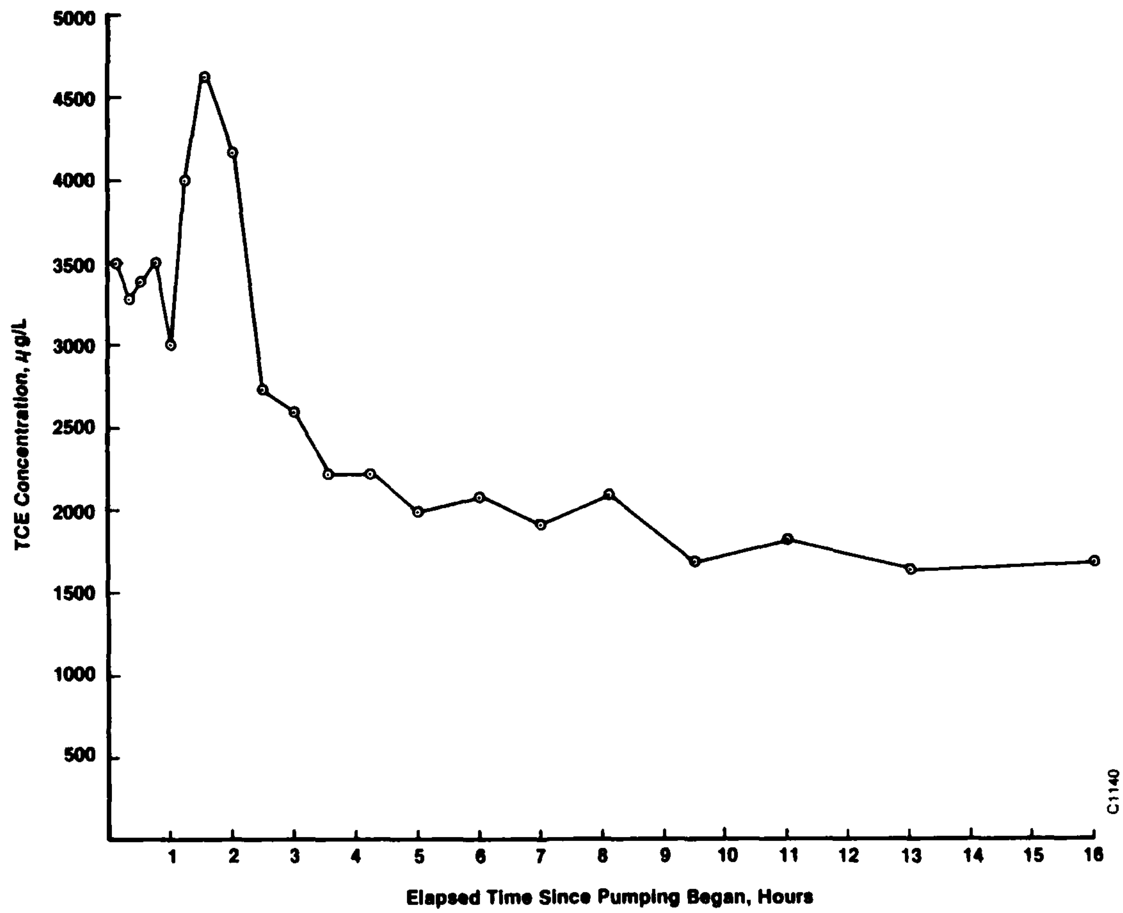

Figure 4-13. Plot of Well 18 Trichloroethylene (TCE) Concentration During Pump Test.

During the pumping period, TCE concentrations declined from a high of 4.6 mg/L to a low of 1.8 mg/L. While the concentrations at the end of the test remained significant, there was a clear decreasing trend. These data are evidence of limited contaminant leakage into the immediate vicinity of the well bore. Had the concentrations remained relatively constant or increased, such data would have been evidence of relatively widespread contamination in the main aquifer. Further evidence for limited localized contamination is the absence of similar quantities of TCE in surrounding wells.

4.3 Significance of Findings

4.3.1 Zone 1 (Landfills 1 through 4)

The hydrogeologic data for zone 1 show conditions consistent with regional patterns and pre-study expectations. The shallow ground water east of the landfills is associated with the surface water in Crutcho Creek. During low flows, the ground water is expected to be effluent to the creek; during high water, the creek waters will recharge the shallow ground water. The deeper wells (1A, 1B and 1C) are completed in a system which is probably separate from that along the creek. The elevation of the water table in these three wells is about 1200 feet, compared to about 1215 to 1220 in wells 3, 4 and 5 along Crutcho Creek. Recharge from the shallow ground water to lower systems would be limited to permeable zones in the dominantly shale strata. The area of Zone 1 is a recharge zone, since piezometric heads decline with depth, as supported by the observation of the water level in core 1D, drilled to a depth of 150 feet (approximately elevation 1082). Three hours after drilling advanced to total depth, the water level was observed at 55 feet below the land surface, at approximately elevation 1183, some 20 feet below the level in wells 1A - 1C.

The measurement of water table elevation in Wells 1A - 1C allow determination of the direction of ground-water flow in the shallowest zones of the sandstone aquifer. Figure 4-14 shows the water table elevations in these three wells and the resultant inferred ground-water flow direction. Flow is

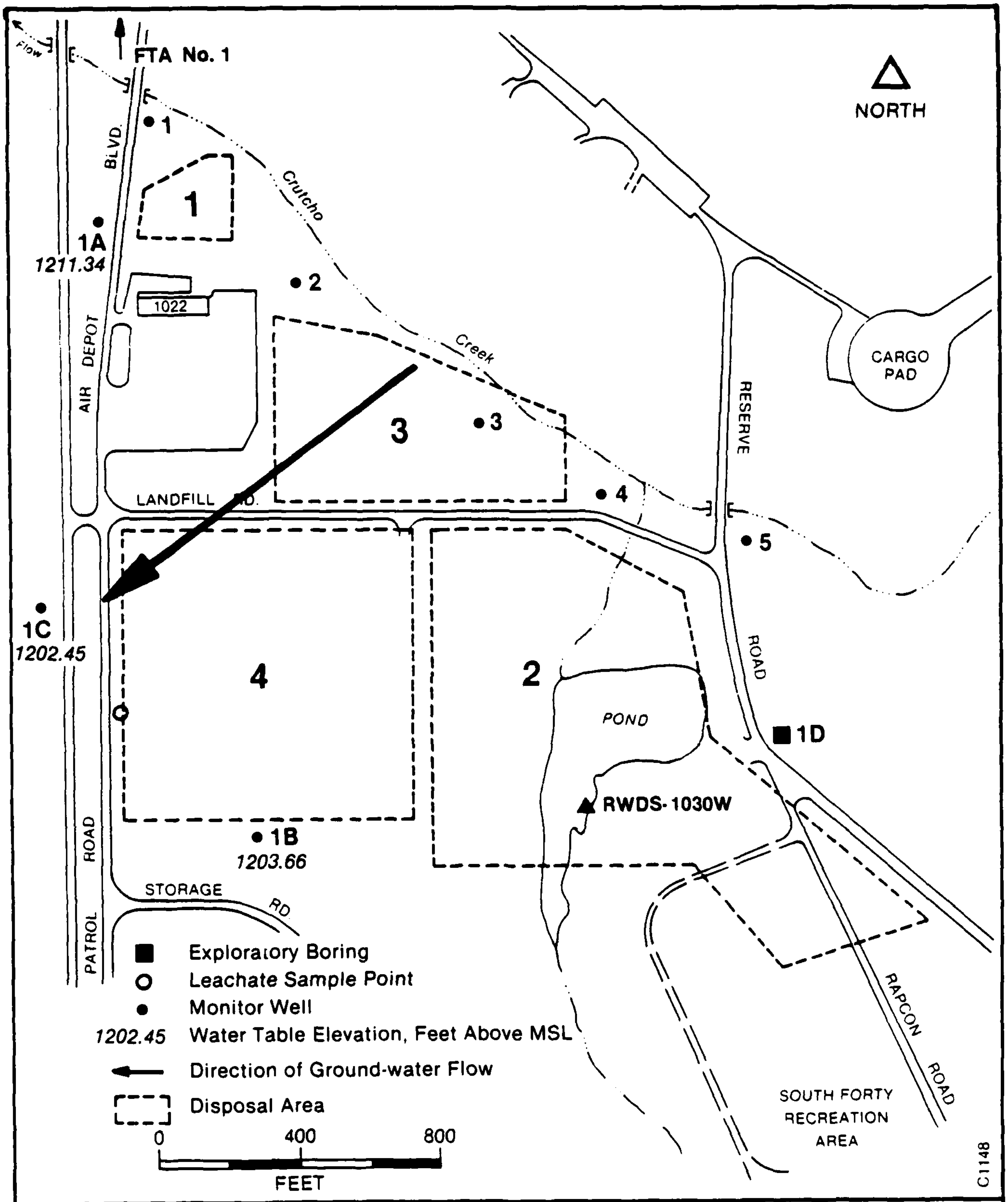

Figure 4-14. Ground-Water Flow Conditions, Zone 1.

to the southwest, in general agreement with the regional system (Figure 2-8). Note that this direction was derived from analytical geometry (three points define a plane in space), rather than from interpreted ground-water contours.

The analytical chemical data for Zone 1 show only limited impact of the landfills on ground-water quality. Of the three deep monitor wells, only the sample from Well 1A shows evidence of contaminant migration to deeper strata. While no human health standards or criteria are exceeded for the analyses performed, levels of total organic carbon (TOC, 5 mg/L), total organic halogen (TOX, 0.08 mg/L), iron (0.025 mg/L) and manganese (0.23 mg/L) are elevated relative to the other two deep wells. The concentration of manganese is also elevated in Well 1A relative to the secondary drinking water standard of 0.05 mg/L.

The State of Oklahoma analytical data (Appendix H) suggests the presence of volatile chlorinated organic compounds in Wells 1A (dichlorobenzene - 5 ppb) and 1C (trichloroethylene - 210 ppb and 1, 1, 2-trichloroethane - 6 ppb). The Phase II (Stage 1) study did not address these compounds. No volatile halocarbon analyses were performed. However, the Phase II (Stage 1) analytical schedule does contain total organic halogen (TOX). This test is used as a screening parameter to test for the likely presence of chlorinated organic species. It is only a screening test, and should not be used for any final determination of the presence or absence of chlorinated compounds. It is subject to low bias due to loss of volatiles during transport and analysis and subject to high bias due to interference by inorganic chlorides. The nominal detection limit is 0.01 mg/L (10 ppb) of chlorine. TOX values reported for monitor wells 1A through 1C range from 0.06 to 0.08 mg/L (60-80 ppb), as chlorine. This is in rough correspondence with the State of Oklahoma GC-MS data, which show some volatile chlorinated organics in all three wells. In general, there is rough correspondence between TOX levels and the GC-MS data throughout the Base. In some cases, the TOX data suggest more chlorinated species were present than were found by the State of Oklahoma; in some cases, less. Additional sampling and analysis would be required to further address this issue.

Of the eight pre-existing monitor wells, only Wells 2 and 4 display contamination. Well 2 yields water with a TOC of 37 mg/L. ; Well 4, water with TOC of 33 mg/L. and TOX of 0.2 mg/L. The concentration of manganese is also elevated in all shallow wells relative to the secondary drinking water standard of 0.05 mg/L. However, these data are at significant variance from the data obtained at the time the wells were drilled (Finn, 1981), when nearly all displayed large quantities of metals and TOC. Without knowledge of the conditions under which those samples were collected or the physical appearance of the samples, it is difficult to assess the cause of the difference between the two sample sets. The earlier data were collected in the fall, when leachate outflow from the landfills, rather than surface water recharge would have dominated the system. Perhaps the earlier samples merely came from a leachate-dominated system which does not persist year round. Periodic samplng over at least one full year would be required to assess the variability of the system. The State of Oklahoma data show volatile chlorinated organics in three of the six wells sampled. TOX is present in four of the eight wells.

The Zone 1 leachate sample was typical of sanitary landfill leachates, high in TOC and iron, but with a TOX value of 1.5 mg/L, suggesting the presence of chlorinated organic compounds.

The pond sample, in spite of being from an impoundment overlying a landfill, did not display elevated levels of contaminants. The presence of the pond remains significant, however, since it provides a driving hydraulic head for recharge through the landfill and resultant leaching of landfilled materials.

In summary, analytical data from the current Phase II (Stage 1) effort document only limited contaminant movement from the Zone 1 landfills. However, outside data (State of Oklahoma, Appendix H; Finn, 1981) suggest that the occurrence of other species and/or seasonal variations may be important.

4.3.2 Zone 2 (Landfills 5 and 6)

Zone 2 consists of two widely separated installations, Landfills 5 and 6. Each will be discussed separately.

Landfill 5

Activities at Landfill 5 were limited to the installation and sampling of a single deep monitor well. Data from pre-existing monitor wells 6, 7 and 8, sampled as part of the Zone 1 effort, also apply to conditions at Landfill 5.

Hydrogeologic conditions at Landfill 5 are very similar to those in Zone 1, which is downstream along Crutcho Creek. The shallow soil zones along the creek contain a water table aquifer which is in hydraulic continuity with the stream. The deeper monitor well (2B) encountered water at approximately 44 feet below land surface. This water is not in hydraulic continuity with that in the shallow aquifer, but may be receiving recharge from it, through permeable zones in the shale. A single data point is insufficient to determine a ground-water flow direction. Regional data (Figure 2-8) suggest a southerly flow at this point.

The analytical data do not provide evidence of significant contamination. No human health standards or criteria were exceeded. Monitor wells 6 through 8 display elevated manganese concentrations (relative to the secondary drinking water standard) and moderate (2 to 14 mg/L) levels of TOC. The deeper well (2B) displays TOC of 5 mg/L. The modified EPA Method 625 data also display a very low (3.2 ug/L) level of butyl benzyl phthalate, for which no human health or environmental criterion exists. Since the phthalate esters are nearly ubiquitous and are often an artifact of the analysis, detection of one at the low ppb level is probably not significant. The State of Okalahoma data (Appendix H) show appreciable levels of dichloroethene (385 ppb) and trichloroethylene (62 ppb) in existing well 6 and lesser quantities in well 7. No purgeable organic compounds were detected in Well 2B.

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Landfill 6

Activities at Landfill 6 were limited to the installation and sampling of a single deep monitoring well (2A) south of the landfill. Preexisting monitor wells 9 and 10, which were dry at the time of their installation (Finn, 1981), were not sampled. Ground water was encountered at a depth of approximately 36 feet below land surface, at approximately elevation 1259. Based on regional considerations, ground-water flow is to the south. The single data point of Well 2A is insufficient to establish local conditions.

The Phase II (Stage 1) analytical data do not provide evidence of ground-water contamination. No human health standards or criteria were exceeded. However, the State of Oklahoma data (Appendix H) report the presence of volatile chlorinated hydrocarbons (dichloroethane - 25 ppb; trichloroethylene - 30 ppb; tetrachloroethene - 12 ppb; and 1,1,1-trichloroethane - 4 ppb). These compounds were not addressed by the Phase II (Stage 1) study.

Sampling activities of the Oklahoma State Department of Health suggest that Landfill 6 is the possible source of contamination of a private well (the Ainsworth Well) off-base, immediately north of Landfill 6. Depth and condition of the well are unknown. Chlorinated organic compounds have been discovered and confirmed to be present in this well.

Summary - Zone 2

In summary, hydrogeologic conditions at both landfills are consistent with regional patterns. The Phase II (Stage 1) analytical data provide little or no evidence of contaminant migration from landfills 5 or 6. However, the State of Oklahoma data (Appendix H) suggest that volatile chlorinated hydrocarbons may be important contaminants at these facilities.

4.3.3 Zone 3 (Industrial Waste Pit No. 2)

The investigations at Zone 3 were designed to define the chemistry and geometry of Industrial Waste Pit No. 2. The geophysical survey results, as approximated by the 80 umho contour on Figure 4-6, may be used to bound the area underlain by significant quantities of wastes. The total area is aprox-imatey 38,000 square feet. The coring results show the waste "body" to be very shallow, less than 5 feet in depth. Therefore, the total quantity of materials present is less than 188,500 cubic feet (7,000 cubic yards).

The soil chemistry results show the waste materials to be high in organics and metals, reflecting the origin of the waste itself. However, both the coring and the analytical results reveal broad variations in both the appearance and chemical content of the materials. This is evidence for the pit closure having been done by pushing or dumping earth materials into the pit and grading over the site.

The results of analyses of ground water show little or no migration of waste constituents downward from the site of the pit. A perched ground-water body exists in a sandstone lens, some 16 to 20 feet below the land surface, sampled with monitor well 3F. The sample from this well (Table 4-8) shows no evidence of contamination, whereas the well completed in the fill material (3G) shows material similar to that found in the soil cores at the site. Concentrations of Cd, Cr, Ni, Pb, Zn and phenol in Well 3G exceed human health standards or criteria. The wet chemistry phenol value of 80 mg/L is probably biased low, due to interferences with the colorometric procedure and the large dilutions required to bring the sample to within instrument range. The 220 mg/L GC-MS value is probably more accurate. The State of Oklahoma data (Appendix H) show large quantities of volatile organic contaminants in Well 3G, only. The TOX data show a similar pattern. The shallowest ground-water (that in the fill or the weathered zone near the surface) is either evaporating on a seasonal basis, or is moving downslope near the surface. The geophysical anomaly in the nearby gully (Figure 4-6) may be due to an overflow feature from the period of pit operation or to continued horizontal movement

of leachate from the closed pit. The fact that a zone of near-background conductivity exists between the pit and the "overflow feature" suggests the former.

The results of the Phase II (Stage 1) investigation show a body of highly contaminated material occupying the site of the former waste pit. The geophysical results indicate that the constituents of this waste are not currently migrating away from the site. Provided that the surface is not disturbed or the effective surface drainage disrupted, it is unlikely that significant contaminant migration will occur.

4.3.4 Zone 4 (Industrial Waste Pit No. 1

The investigations at Zone 3 were designed to define the chemistry and geometry of the remains of Industrial Waste Pit No. 1. However, in contrast to conditions at Zone 3 (Industrial Waste Pit No. 2), the remains of the pit are very diffuse and not well defined. The various geophysical surveys show only one significant anomaly, with the balance of the area occupied with materials near or only slightly above background conductivity. The coring results show the waste materials to be shallow and more thoroughly mixed with soil. On the basis of available data, no reliable estimate can be made of the total volume of materials present.

The soil chemistry results show the waste materials to be high in organics and metals, reflecting the origin of the waste itself. The highest levels of contamination were found in the sample (4E.3) from near the conductivity anomaly. Both the coring and the analytical results reveal broad variations in both the appearance and chemical content of the materials. This is evidence for the pit closure having been done by pushing or dumping earth materials into the pit and grading over the site, just as apparently was done at Zone 3.

The results of analyses of ground water show little or no migration of waste constituents downward from the site of the pit. Unlike Zone 3, no

perched ground-water body exists, even though a sandstone lens exists some 14 to 20 feet below the land surface, sampled with monitor well 4F. This well (Table 4-11) remained dry throughout the period of observation. The well completed in the fill material (4G) shows some contamination (TOC, lead phenol), but less than that in the soils at the site. The deep monitor well (4A) does not display evidence of significant contamination of the ground water at the site. Contaminant concentrations in both wells are below human health standards or criteria. However, the State of Oklahoma data (Appendix H) reveal approximately 100 ppb of TCE, along with 8 ppb of diethyl phthalate and 3 ppb of 1,2-dichloroethane in Well 4A, but "No purgeables detected" in Well 4G. The shallow ground-water (that in the weathered zone near the surface) does not appear to be substantially recharging the ground water, but is either evaporating on a seasonal basis, or is moving downslope near the surface.

The results of the Phase II (Stage 1) investigation show a diffuse zone of contaminated material occupying the site of the former waste pit. It further appears that the constituents of this waste are not currently migrating away from the site. The surface slope of Zone 4 is lower than that of Zone 3, which provides more opportunity for infiltration of precipitation and occasional standing water. However, there is only limited opportunity for waste constituents to begin to migrate, because of the geologic containment provided by the relatively impermeable shale bedrock.

4.3.5 Zone 5 (Base Water Supply Wells)

Pump samples were collected from the 20 operational Base water supply wells (out of a total of 27 existing wells). Of the 20 wells sampled, only six displayed any trace of chlorinated organic contaminants. Observations concerning the contamination in each well are provided below.

Well 9, located north of the base along Midwest Boulevard, had not been in service for over six months when sampled. It could be pumped for only

five minutes, so the sample represents an inadequately purged, stagnant system. At the present time, very little can be said concerning the occurrence of the chlorinated hydrocarbons in this well. The concentration of chloroform (2.1 ug/L) does exceed the EPA toxicity criterion of 1.9 ug/L (Table 4-2). Until the well can be adequately purged, no further diagnostic testing can occur. The maintenance records should be flagged for resampling when the well is brought back on line.

Well 5, located in the western portion of the Base, is not associated with any obvious contaminant source; it is approximately 2,000 feet north of Landfill 1, the closest waste disposal area. The reported occurrence of a single chlorinated organic compound at (trans-1,2-dichloroethene) at a low level (1.7 ppb) is probably not significant. Further, there has been no toxicity guideline established for trans-1,2-dichloroethene (Table 4-1). This well should be resampled during a future activity.

Wells 14, 16, 18 and 19 are all in the vicinity of the Oklahoma City Air Logistic Center (Building 3001). Results of analyses are discussed in the context of Zone 6 (Building 3001 wells) in Section 4.3.6, below. Wells 18 and 19 are the specific object of study at Zone 6; Wells 14 and 16 are located east and northeast of the facility. It is noteworthy that none of the other wells in this area display any contamination.

With the exception of wells in the vicinity of Building 3001, all Base water supply wells appear to be substantially unaffected by contaminant migration from Base waste disposal sites.

4.3.6 Zone 6 (Building 3001 Wells)

The testing at Zone 6 consisted of a protracted pumping and sampling of Well 18. Additional data are available from the synoptic sampling of all Base water supply wells (Zone 5). During the 16-hour pumping period, TCE concentrations in the Well 18 discharge declined from a high of 4.6 mg/L to a low

of 1.8 mg/L. While the concentrations at the end of the test remained significant, there was a clear decreasing trend. These data are evidence of limited contaminant leakage into the immediate vicinity of the well bore. Further evidence for limited, localized contamination is the absence of similar quantities of TCE in surrounding wells. Wells 14, 16 and 19 contain small quantities of trichloroethylene, tetrachloroethylene, and dichloroethane (Table 4-13). However, none of the contaminants are present in concentrations exceeding EPA toxicity guidelines (Table 4-2).

Based on the results of the Phase II (Stage 1) investigation, conditions at Zone 6 consist of a zone of contamination, dominantly trichloroethylene, of unknown source and extent, in the vicinity of Building 3001. The occurrence of significant contamination is limited to relatively shallow zones. This contamination is moving downward in the immediate vicinity of the water supply wells themselves, and is being entrained in water pumped by these wells. The most prominent occurrence of contaminants is in Well 18, which has been taken out of service.

There remains the issues of investigating the occurrence of TCE in the shallower zones and sealing off the water supply well casings to prevent further downward migration of contaminants. Consideration of the issue of sealing wells to prevent further migration (remedial action) is beyond the scope of this investigation and was treated in separate correspondence with the Base. The investigation of the occurrence of TCE in the shallower zones is discussed in Section 5.0.

5.0 ALTERNATIVE MEASURES

This section discusses the alternative measures available for actions at each of the zones investigated. As was discussed in the introductory material in Section 4.0, the occurrence of contaminants is significant primarily within the context of threats to a receptor. Alternative measures are considered as they relate to evaluating issues of exposure to candidate receptors. The prime receptors to be considered are the regional Garber-Wellington aquifer, a major water supply source, and the installation boundary, a de-facto receptor. All zones (Figure 5-1) have the potential to impact the Garber-Wellington. Zones 2 (Landfill 6) and 6 (Building 3001) have the potential to impact the installation boundary. The categories of measures to be considered include:

- o Continued monitoring of existing wells;
- o Installation of additional monitoring wells;
- o Initiation of other sampling; and
- o No further activities.

5.1 Volatile Hydrocarbon Sampling and Analysis

The Oklahoma State Depafment of Health split samples with the Radian team for much of the monitor well sampling effort. The state samples were analyzed for volatile organic by GC-MS, an analytical procedure not addressed in the Phase II (Stage 1) Statement of Work, other than for selected Base water supply wells. Significant quantities of chlorinated hydrocarbons (dominantly solvents) were discovered in several portions of the Base. Since the occurrence of chlorinated organic compounds in the ground water at the Base is an important discovery, and since all of these analyses were done by GS-MS, a semi-quantitative method, it is appropriate to verify the observations by resampling and analysis by gas chromatography, a more accurate method of quantitation. The available alternative measures are:

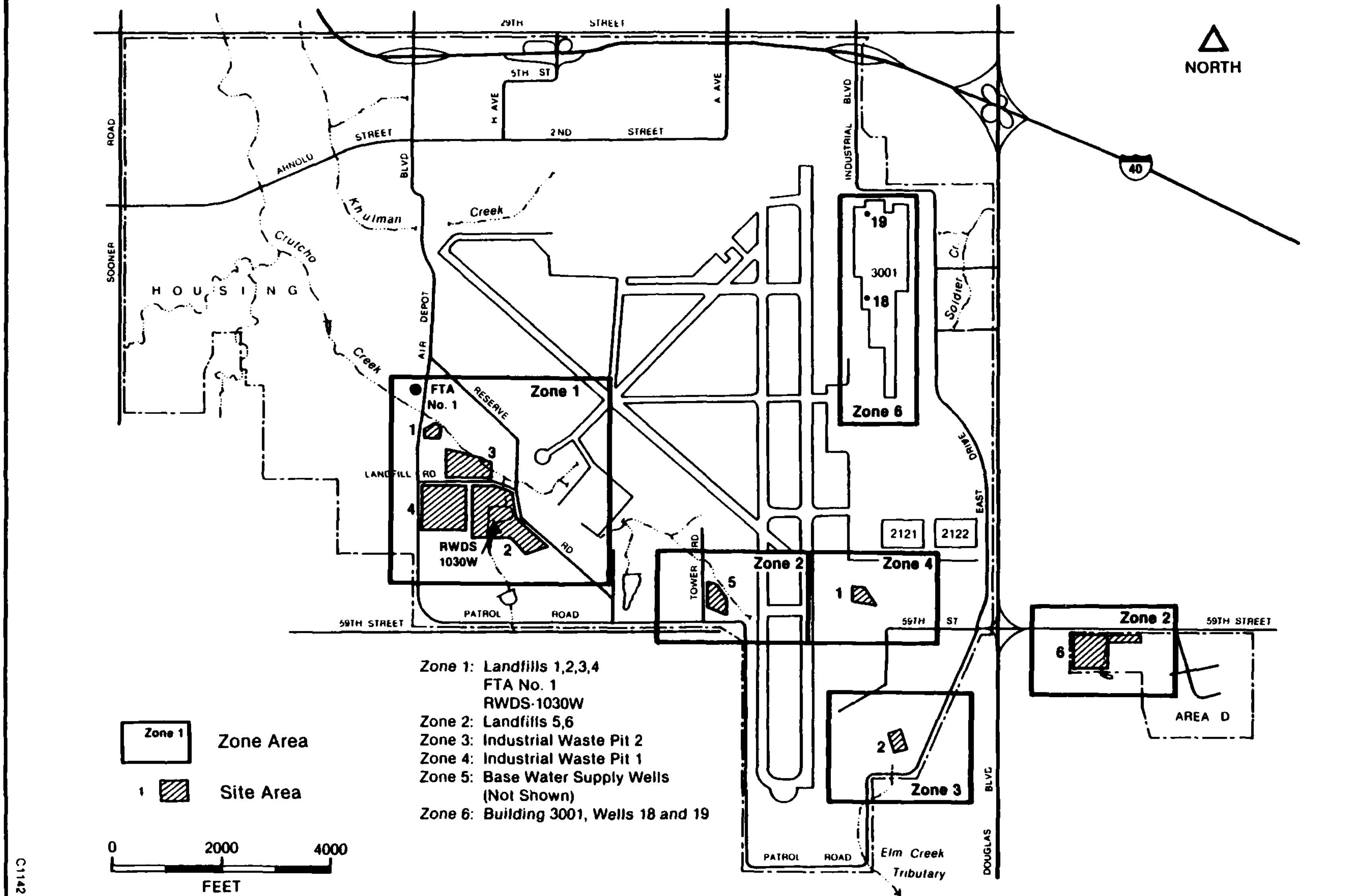

Figure 5-1. Zones of Investigation, Tinker AFB.

- Accept the State sampling data without comment or followup.

- Repeat the State sampling and analysis, utilizing the same procedures (GC-MS). This would provide an independent verification of the State data.

- Repeat the State sampling, but with analysis by GC (EPA Methods 601 and 602). This would combine an independent verification with more accurate quantitation.

Radian recommends resampling all wells for volatile organic compounds, with analysis by gas chromatography (EPA Methods 601 and 602 with provision for double columns). The following discussions of data needs at each zone presuppose the recommended resampling.

5.2 Zone 1 (Landfills 1 through 4)

Knowledge of ground-water flow conditions at Zone 1 is adequate to define the environmental impacts of the landfills. However, the chemical quality of ground water sampled by the existing monitor wells along Crutcho Creek is not sufficiently well described. The differences between observations at the time of drilling (Fall of 1981) and at the time of the Phase II (Stage 1) effort are large and need explanation. The most plausible explanation is that of seasonal variation in ground-water quality. The available alternative measures are:

- Consider that the original samples represented a period of the year when leachate dominated the shallow ground-water system and that the Phase II (Stage 1) samples represented a period when bank storage (recharge from the stream) dominated the system. Assume that the two samples describe the extremes of the system and interpret ground-water impacts accordingly.

- o Conduct a quarterly sampling program for a period of one year to verify and quantify the seasonal variation. This also provides an opportunity to validate one or both sets of existing data.

Radian recommends accomplishing the sampling program. The unsupported acceptance of the existing data set is technically unsound.

5.3 Zone 2 (Landfills 5 and 6)

Alternative measures for each landfill are discussed separately.

5.3.1 Landfill 5

The historical environmental effects of this landfill are adequately described by the existing data. Considerations of the data from Wells 6-8 along Crutcho Creek are the same as discussed for Zone 1. However, as noted in the narrative of the field program (Section 3.0), the surface of this landfill has been disrupted by current construction activities in the area. The condition of the landfill and its probable environmental effects should be reviewed when the construction activity is concluded.

5.3.2 Landfill 6

Conditions at Landfill 6 are the subject of an ongoing study (Phase II Stage 2). Therefore, no additional alternative measures are considered as part of this report. The Statement of Work for Delivery Order 21 provides for a network of four deep and three shallow wells to be drilled north of Landfill 6. These wells will document the hydrogeologic relationship between the landfill and a contaminated private well (the Ainsworth well) located north of the landfill.

5.4 Zone 3 (Industrial Waste Pit No. 2)

The existing hydrogeologic and chemical data are sufficient to describe current conditions and to evaluate the probable environmental effects of the pit. Therefore, no additional work need be planned for this Zone. Provided the existing land use and cover are maintained, no changes in impacts are anticipated.

5.5 Zone 4 (Industrial Waste Pit No. 1)

The existing hydrogeologic and chemical data are sufficient to describe current conditions and to evaluate the probable environmental effects of the pit. Therefore, no additional work need be planned for this Zone. With the exception of one small area, there appear to be very few traces remaining of this facility.

5.6 Zone 5 (Base Water Supply Wells)

With the exception of wells in the vicinity of Building 3001, discussed below, all the Base water supply wells appear to be substantially unaffected by USAF waste disposal activities. With this finding, no further IRP-related activities are contemplated. However, the occurrence of volatile chlorinated hydrocarbons has been documented at the Base. Therefore, some consideration should be given to establishing an ongoing Air Force sampling program with analysis by EPA Method 601, as part of the normal drinking water surveillance activities. For most wells, annual sampling and analysis is appropriate. For wells adjacent to "problem areas" such as Building 3001, semi-annual sampling is appropriate.

5.7 Zone 6 (Building 3001 Wells)

Hydrogeologic conditions and chemical contaminant occurrence in the vicinity of Building 3001 are not well known at the present time. Substantial quantities of TCE are known to exist in Well 18, along with lesser quantities

of other volatile halocarbons. Wells 14, 16 and 19 also contain small quantities of volatile halocarbons. Testing of Well 18 shows the contamination to occur in the shallow portions of the aquifer. The probable means of entry into the water supply wells is by leakage along or through the casing or wellbore.

Conditions in the vicinity of Building 3001 are the subject of an ongoing investigation (Phase II Stage 2), which will address the major concerns of contaminant sources, occurrence and movement. Therefore, no additional alternatives are addressed in this report. The Stage 2 study will include the following elements:

- Installation of seven deep monitoring wells in the area east of Building 3001 to investigate contamination which may exist in the shallowest portion of the regional aquifer;

- Execution of a survey for buried pits and tanks in the vicinity of Building 3001 to identify possible contaminant sources; and

- Measurement of the depth to static water level in the Base water supply wells to establish regional ground-water flow patterns.

6.0 RECOMMENDATIONS

This section contains the Phase II IRP recommendations for further actions on Tinker AFB. The recommendations are listed below in order of priority with the most important activity first. The selection and prioritization criteria are:

- o Resolution of issues concerning possible receptors; and
- o Resolution of issues concerning contaminants of interest.

Specific recommendations are as follows:

1. Investigate hydrogeologic conditions and contaminant occurrence in the vicinity of Building 3001, as provided in Stage 2.

2. Investigate hydrogeologic conditions and contaminant occurrence in the vicinity of Landfill 6, as provided in Stage 2.

3. Investigate the occurrence of volatile halocarbons and aromatics in all monitor wells by resampling and analysis by EPA Methods 601 and 602.

4. Investigate the seasonal variations in water quality in the existing monitor wells along Crutcho Creek by conducting a quarterly sampling program for a period of one year. Analysis should be for total organic carbon, total organic halogen, and the metals on the parameter list in the current Statement of Work: Fe, Mn, Cd, Cr, Ni, Cu, Zn, Pb and Hg.